EFFECTS OF SHAPE, LETTER ARRANGEMENTS, AND PRACTICE ON TEXT ENTRY ON A VIRTUAL KEYBOARD

A Thesis
Presented to
The Academic Faculty

by
Marita A. O'Brien

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Psychology

Georgia Institute of Technology
August 2006

EFFECTS OF SHAPE, LETTER ARRANGEMENTS, AND PRACTICE ON TEXT ENTRY ON A VIRTUAL KEYBOARD

Approved by:

Dr. Wendy A. Rogers, Advisor
School of Psychology
Georgia Institute of Technology

Dr. Arthur D. Fisk
School of Psychology
Georgia Institute of Technology

Dr. Bruce N. Walker
School of Psychology
Georgia Institute of Technology

May 18, 2006

ACKNOWLEDGEMENTS

I am very grateful to many people in the Human Factors and Aging lab for their support of this project, particularly Wendy Rogers and Dan Fisk for beginning this line of research and advising me on all aspects of the related studies. Special thanks also go to Mark Richman for his ideas on the first two experiments in this research area and for programming these experiments. I would like to thank Deere & Company for assistance in funding this research, and Jerry Duncan and Bruce Newendorp for their advice and support of this research. This research was also supported in part by a grant from the National Institute of Health (National Institute of Aging) Grant P01 AG17211 under the auspices of the Center for Research and Education on Aging and Technology Enhancement (CREATE) and by the National Institute of Aging Training Grant R01 AG15019. Much love and gratitude to my parents and family, especially my sisters, who've encouraged me and helped with all the other details of my life. Finally, I thank God for His knowledge, wisdom, and love that have directed and sustained me as I've achieved this milestone.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

This research study examined the design of a virtual keyboard that can be used for text entry with a rotary controller, particularly when users may differ in age and experience with a particular system. I specifically examined the shape and letter arrangement on the virtual keyboard to help determine the best features to use in a design. Two keyboard shapes, an Oval and a Plus, were selected to represent different aspects of the shape. Two keyboard arrangements, Alphabetic and a Standard QWERTY-based ordering, were selected to represent a well-known and less familiar arrangement. In the experiment, older and younger adults entered words over two consecutive days. Most of the time, they used either the Oval or the Plus, but they also used the alternate shape at specific points during their practice session to allow assessment of their ability to transfer what they had learned. At the end of the second day, they also used a variation of the practiced arrangement to examine how well they had learned the letter arrangement.

Text entry performance on both shapes improved as a function of practice, demonstrating that participants could learn even unfamiliar devices and virtual keyboards to complete a word entry task. No overall shape effects were found for any level of performance, but shape did affect how participants learned and performed the word entry task. In particular, unique visual features on a shape may facilitate memorization of letter/visual cue mappings. These shape features are particularly important for older adults, as younger adults seem to develop a mental model that helps them memorize letter locations on either shape. With practice, older adults could achieve optimal performance levels with an Alphabetic keyboard on the Plus shape that has the more visually unique corners. In general, alphabetic ordering is best not only because it helped visual search, but also because it facilitated better movement planning.

Overall, designers should consider creating unique visual features on a virtual keyboard that will blend with the compatibility and allowed movements for the selected device to create an effective virtual keyboard.

INTRODUCTION AND BACKGROUND

As computers become more ubiquitous, designers are challenged to develop device controls and displays for different types of interaction goals. Some devices, such as laptop computers, are specifically designed for optimum flexibility in a variety of computer programs. Other devices, such as in-car navigation systems and television controllers, manage only a few functions within a limited domain. Designers of these systems can then optimize the controls and displays for these limited functions, but they may also have to create a unique input technique for low-frequency functions as well.

A recurring requirement across various devices is text-entry capability to support occasional searches and comment input, such as entering an address on a mobile navigation device. Different devices have included different solutions even for just the text entry display. Hertz's NeverLost, for instance, (Figure 1), displays letters in three 3x3 squares for the first, second and third sets of letters in the alphabet. Many arcade games provide a rectangular list of letters in the standard QWERTY order regardless of the type of input device used. This variety is not surprising because little research has been conducted to systematically identify the specific features of a virtual keyboard that are important to consider for occasional text entry with a non-standard device.

Figure 1. Display used for entry of cities with NeverLost control in the Hertz navigation system.

There are several research areas that can be leveraged to better understand the relevant factors. Numerous studies have been conducted to improve design of new controls and to guide the appropriate selection of a control given a particular task (e.g., Baber, 1997; Douglas & Mithal, 1997; MacKenzie & Soukeroff, 2002; Rogers, Fisk, McLaughlin, & Pak, 2005). A few studies have also examined how control features and display features interact in movement tasks through affordances, providing additional guidance on important considerations and design options (e.g., Newell, 1991; Polson & Lewis, 1990). In addition, extensive research has been conducted to examine the optimum layout for keyboards used in typing and mobile applications for experienced users (MacKenzie & Soukoreff, 2002; Norman & Fisher, 1982; Plaisant & Sears, 1992).

This research still leaves specific gaps relevant to intermittent usage and to individual differences among users such as age, as well as a broader gap relating to the interaction of movement and visual search components of the text entry task. The purpose of the current study was to address these gaps by answering four research questions. First, is the interaction of the different components of the task, primarily movement and visual search, affected by characteristics of the keyboard shape? Second, given a novel device with specific movement constraints, what affordances on a virtual keyboard are relevant for text entry? Third, given that there are age-related differences in movement and visual search, are the shape affordances perceived and used differently by users with a range of ages? Finally, does direct experience affect how text entry is completed on a virtual keyboard?

The present experiment examines these questions with the non-standard device shown in Figure 2, a rotary controller, though I wanted to identify factors that could be considered for a broader set of devices. The background section of this paper reviews research on the task factors of text entry, describes the affordances of the target environment, presents research on age-related differences in these task factors, and outlines possible impacts of usage with experience. Each area discussion concludes with a summary of the key items that were addressed in the study.

Figure 2. Rotary controller used in experiment.

Task Factors

Conceptual Model

Text entry on various devices has been examined in the psychological and human computer interaction literature primarily by individually examining and optimizing the movement or visual search components of the task (e.g., MacKenzie & Soukoreff, 2002). For example, Zhai, Hunter and Smith (2002) focused on visual search in their keyboard design because of their assumption that the entry time for novice users on virtual keyboards would be determined less by the time to move a cursor to a target but more by the time to search and find keys. In contrast, research for mobile devices has focused on optimizing movement based on the assumption that there is no visual search time for experts (MacKenzie, 2003). In both examples, feature manipulation and testing have typically focused on one or the other component of the task. Although these studies identified ways to optimize the overall text entry task through specific movement or visual search selections, the studies did not clearly discuss any interactions. The studies also did not address the effect of a user experience that was neither novice nor expert such as an intermittent usage pattern in which individuals use a device for only a short period each day.

Movement Optimization

A brief review of two psychological models for movement control will illustrate relevant features of the virtual keyboard. One psychomotor model comes from Walker, Meyer, and Smelcer's (1993) model which lists three phases of movement execution: initiation, execution, and verification. Although execution and verification times are based on width and distance, initiation is based on planning, definition of path, and coding of movement direction. Researchers have found that even subtle movement intention changes such as change in direction can influence the ease of specific movement planning (Michaels, 1988). Thus, a system with compatibility between the input device's perceived movement control and actual control can improve movement initiation by communicating more clearly the impact of a movement decision, which can improve reaction time.

Another psychomotor model is Meyer's stochastic optimized submovement model (Meyer, Abrams, Kornblum, Wright, & Smith, 1988). This model defines a movement as a series of primary submovements, motor noise and secondary submovements. Initial research suggests that the primary submovement is programmed to minimize the average total movement duration. In addition, the primary submovement is faster and more accurate than the secondary submovements. Thus, participants seemed to prefer to move quickly and use online visual feedback to make discrete error corrections rather than fully planning a move (Kahn & Franks, 2000). Thus, an environment with clear visual feedback may lead participants to reduce movement time by producing many rapid movements rather than carefully planning the movements to reduce the total distance moved.

Another study found that not only spatio-temporal information (such as angle mapping) but also information of any kind can directly and flexibly be used for motor control and learning (Mechsner, 2004). Perceptual noise may affect the programming of the initial movement, but noise effects are only incorporated in the programming of the secondary/corrective submovements based on system feedback (Douglas & Mithal, 1997). Thus, feedback is important for programming both primary and secondary submovements, although the effects may be different.

These models suggest two possible aspects of the shape that affect movement: compatibility and feedback. Compatibility between the control and the keyboard shape may affect movement because perceptions of the required movement plan may differ based on the virtual keyboard shapes. In addition, differing requirements for visual monitoring on different shapes or letter arrangements may change the user's ability to adjust the strategy and submovement planning. Overall, movement performance might be dependent on the virtual keyboard shape. Users may learn how to use the rotary knob effectively on one shape with specific planning, path definition, and direction coding, but fail to generalize that knowledge to the knob itself. This result would be suggested if users can not effectively transfer learned movement performance to another shape. On the other hand, movements with the rotary knob may be independent of the shape of the virtual keyboard on which they are moving. This explanation might be supported by experimental results in which user performance trajectories are unaffected by transfer to another shape. The current research study examined movement performance in conjunction with the visual search components, discussed in the next section.

Visual Search

Several screen features have been identified from visual search research that affect identification of specific items on a display. These include overall density, local density, icon grouping, and layout complexity (Tullis, 1983). For a virtual keyboard, this means two things. First, visual search is improved when letters, numbers, and symbols are placed close together, though with sufficient white space to distinguish individual items. Second, visual search is facilitated when items are grouped logically and hierarchically, allowing a portion of the search process to select between groups before selecting between items in a group. Finally, simplifying the overall organization of items on the display can also guide a more systematic search that not only reduces search times, but provides users with control over visual navigation search times (Hornof, 2004). Within the overall display, provision of cues that are clearly separable and identifiable within the user's control strategy can therefore help performance.

User expectations influence how individuals learn visual search strategies. One study has found numerical performance improvement for display organization and schema that conforms to user expectations (Nielsen, 1999). In Nielsen's study, the success rate for product search was 80% when the navigation schema conformed to user expectations/mental model, but only 9% with unfamiliar expectations/mental model. Another study, though, found that users do adapt their navigation strategy rapidly to a change in display layout (McCarthy, Sasse, & Ringelsberger, 2003). This adaptation confirmed an initially surprising finding that an alphabetic arrangement of letters on a typing keyboard lost its advantage after a short training period keyboard (Norman & Fisher, 1982). The researchers inferred that users could just as easily search a non-alphabetic keyboard as they could mentally process a strategy that required computation of the relative order of the target from the previous letter and comparison across a memorized mapping of the alphabet on a three-line keyboard. Intermittent users, however, may not learn any strategy that is not already well-learned or clearly apparent from the design shape or layout.

In summary, features of a keyboard shape that might affect visual search are overall density, local density, icon grouping, layout complexity, and user expectations. Research does not, however, identify which feature is most important for intermittent users. If the keyboard shapes provide sufficient discrimination capabilities and cues in a familiar search pattern, performance should improve with experience. This was tested in the current study by changing a keyboard shape and examining whether this hinders performance by interfering with a well-learned strategy. On the other hand, use of an unlearned keyboard layout should force a systematic search that will not leverage visual search cues regardless of shape.

Interaction of Movement and Visual Search

While many studies have examined either the movement or visual search aspect of a text or data entry task, few have explored the interaction of these components. In one study that examined keying accuracy and speed for a data entry task, researchers found that both dependent variables were affected by the logic imposed by the keyboard for search and movement (Butterbaught & Rockwell, 1982). Speed was generally more variable across trials, and learning of a non-intuitive layout took longer than an intuitive layout. A more recent study that separated the visual search and movement tasks for limited use with a rotary knob found that different keyboard shapes were faster for different tasks (O'Brien, Rogers, Richman, & Fisk, 2005). This study only required individual movements and single letter search rather than word entry, however, so there was no interaction of the two components.

Another aspect of the interaction for text entry with a rotary knob is derived from the common use of the selection method for this task. With this method, the cursor is sequentially moved around the display screen to highlight a single character that is then selected (Bellman & MacKenzie, 1998). This method requires many movements per character and visual attention to monitor the cursor position before each selection, which may affect the choice of strategies for the task. Additionally, one study noted that the high need for visual attention from the selection method may be a source of frustration for users (Wobbrock, Myers, Aung, & Lopresti, 2005). This frustration could reduce the user's motivation to learn better strategies as opposed to continuing use of initial strategies that seem to work well enough.

Relevance of Task Factors Research

Previous research provided guidance for the current research by pointing to the individual movement and visual search components of the text entry task, but there were limitations in that research that were explored in the current study. First, the movement research on rotary knobs does not indicate which aspects of a keyboard shape affect movement planning and performance most heavily. Second, the visual search research does not indicate how learning strategies and expectations could be affected by different cues from different shapes and layouts. Third, the interaction of these components has only been explored in limited domains that are difficult to generalize. This study was aimed at identifying specific aspects of the keyboard shape that affect movement and visual search individually and through interactions.

System Affordances

Affordance Definition

One set of factors that psychologists incorporate in the analysis of potential usability for a new technology or computer system is the set of affordances offered by the device. An affordance is the invariant combination of “variables that are perceived aspects of the medium, substances, surfaces, objects, places and animals that offer some constraints and abilities that can be done with them by a given animal” (Gibson, 1978, p. 143). The affordances of a control provide the user with knowledge about what the device might be able to do, even if he or she has not used this particular device before. For example, a chair affords sitting and a knife affords cutting. Generally, though, user perceptions of affordances arise from an individual’s experiences that suggest a range of possible capabilities, so common perception of constraints of a control is a good baseline for creating new functions (Norman, 1990). Researchers have suggested that these constraints guide the exploratory activity of new learners, helping them to guess about the boundaries and critical regions of the field of operation (Newell, 1991; Polson & Lewis, 1990). Through this exploration, learners can discover regularities in the environment and relationships between the control and display without any conscious effort or awareness of what they have learned (Wulf & Schmidt, 1997). The affordances provide an approach to decreasing the amount of learning required for each interaction experience by providing a natural mapping of the task to the control and display (Hutchins, Hollan, & Norman, 1985).

Discovery of the individual cues to appropriate movement and search techniques can aid identification of designs that support natural learning. One definition of learning comes from schema theory whereby learning is a result of the acquisition of a more appropriate mental representation of the task (Shea & Wulf, 2005). As the tasks are practiced, execution variety aids in creation of a more robust mental schema that is updated based on feedback from each execution. Novices and intermittent users may not vary their activities sufficiently to develop a very robust schema, but they can still benefit from surface features of a system that trigger selection of the most relevant schema each time the user approaches the system (Besnard &

Cacitti, 2005). Thus, psychologists can analyze the usability and learning capabilities of a new system by examining the specific control affordances and perceptual feedback from these affordances to the user.

Device Characteristics

Research from several studies has identified the fundamental affordances of a rotary device such as the rotary controller selected for this study. Several immediate affordances that are perceived from a rotary knob are that the knob is graspable and turnable, with a clockwise turn indicating increasing values (Bradley, 1959). A rotary knob may also provide kinematic feedback about the relative angle of a selector relative to the cursor on the display (Mackinlay, Card & Robertson, 1990). A rotary knob is indirect, requiring visual attention for feedback and determination of cursor position on a display. This indirectness may cost performance by increasing the cognitive resource requirement as the user transforms feedback into a robust schema of all the system capabilities (Hutchins, Hollan, & Norman, 1985; McLaughlin, 2003). Some users may benefit from use of a rotary knob for computer input, however, because the knob restricts selection on the display to only the relevant options (Rogers, Fisk, McLaughlin, & Pak, 2005). This benefit may be more relevant for intermittent users who may not get sufficient experience to develop a robust system schema.

In addition to the fundamental affordances of a rotary knob, the rotary controller also has several other affordances that are perceived through other senses and may affect performance on text entry tasks. These include audible clicks heard as the knob is rotated and tactile feedback felt as the selector moves from position to position. These additional perceptions have been found to reduce response times on a device by implicitly reducing visual load and by increasing finger velocity (Kahn & Franks, 2000). As long as the feedback is rapid, the user can get the feeling of acting directly so that they can modify their intended actions even as the actions are being executed. (Hutchins, Hollan, & Norman, 1985). Thus, the use of kinematic and kinetic information feedback can facilitate motor learning on new technologies (Newell, 1991).

In summary, the affordances of a rotary controller that may affect usability and learning are the fact that it is graspable, turnable, indirect, and constrains movement on the display. Four types of feedback that might affect motor learning are provided by the rotary knob: kinematic, audible, tactile, and visual. The current study focused on issues related to visual feedback that might be differentially affected by the different shapes.

Relevance of System Affordances Research

Perception of cues and constraints guide the natural exploratory activity of users with different experience levels. Usage may change as users become more aware of the device schema within the keyboard shape, which may overcome the initial affordances perceived. Users may also become more aware of how the non-visual feedback supports their understanding of rotary knob movement within the shape. How these cues and feedback work for the rotary knob in a text entry task, however, has not been examined before. The selected shapes and layouts have different affordances that should drive the selection of different schema for movement and search strategies. The generalization and interaction of these strategies were analyzed in the current study by examining what was learned when the task is transferred to a different shape.

Age-Related Factors

Previous Text Entry Research for Older Adults

Text entry for older adults has been examined in a limited number of studies. For instance, Salthouse (1984) evaluated the components of standard typing skill and compared performance across age groups and user skill. He found that performance differences were based on different strategies and motoric performance between age groups and skill levels. These findings suggest that different design criteria must be considered for older adults of a text entry device. Another study that examined text entry and pen-based computer usage across different age groups (Wright et al. 2000), however, found that problems with the pen-based computers were not limited to the older adults. Instead, problems were also found in the younger and middle-aged adults. These findings suggest that design improvements for new input controls and displays could benefit all users. Thus, researchers can expect that any problems identified for older adults may provide useful guidance to improve usability and learning capability for adults of all ages.

Older Adults and Input Devices

Several research studies examining age differences for different input devices have been conducted that highlight differences that might be expected in a text entry task with a rotary device. In one study, younger and older adults used touch-screens and rotary devices to perform movement and selection tasks under different attentional conditions (McLaughlin, 2003). Overall, they found that different age groups had better performance with different devices under differential attentional conditions and task types. Performance for the rotary device was less variable for both age groups. Most relevant to a task entry task, older adults performed better with the rotary device on precision tasks with high attention availability; younger adults performed equally well with either device. Another study examined age differences between younger, middle-aged, and older adults on cursor control tasks with a light pen versus a mouse (Charness, Holley, Feddon, & Jastrzembski, 2005). They found that older adults were slower than the other age groups, but older adults improved their response time more than the other age groups in the first two blocks of practice. Thus, older adults may be able to reach the performance level of younger adults with sufficient practice given an appropriately chosen device and interface.

Older Adults and Movement Findings

Several research studies examining age differences in movement planning and performance have identified expected differences, though the absolute amount and pattern of differences are still inconclusive. One movement study, for instance, found that older adults spend more of the total movement time in the final tuning of submovements than younger adults (Walker, Philbin, & Fisk, 1997). Another study found that older adults showed no reliable effects of practice or movement pattern consolidation even after ten blocks of ten movements, even though younger adults showed these effects after only several dozen trials (Pratt, Chasteen, & Abrams, 1994). These researchers suggested that younger adults may learn how to use feedback to make corrective movements with practice that older adults do not, possibly due to perceptual processing declines. Given the support for motor learning provided by the feedback of the rotary knob, perceptual processing declines may be the source of learning limitations for older adults. Another possibility is that the difference in practice effect is due to cognitive differences, as found by a study in which older adults were slower in preparing short movements versus long movements whereas younger adults were slower in planning long movements (Stelmach, Goggin, & Amrhein, 1988). These researchers suggested that movement plan restructuring for direction and rate change with age. In summary, no study has been found examining movement planning specifically for usage with a rotary knob, but the current study was designed to examine practice effects in particular by providing more experience on each shape before changing it.

Older Adults and Visual Search Findings

Research on differences between user age groups for effective visual search has been more conclusive. Previous research has found that younger adults were more likely to use memory searches or expectation-based searches for the letter entry task than older adults (O'Brien et al., 2005). Thus, shapes with more separable visual cues are more likely to facilitate younger adult performance improvements over older adult performance improvements. Separable visual cues may also operate like consistent mapping (CM) visual search training in which participants always use visual elements in the same way across trials (Fisk, Cooper, Hertzog, Anderson-Garlach, & Lee, 1995). If they do, the Fisk et al. study suggests that older adults will improve search times by using the same learning mechanisms as younger adults, though transfers to other conditions have different effects if the transfer components interfere differently with the task strategy. In addition, older adults are more likely to retain a visual search strategy over a memory retrieval strategy even with substantial practice on the memorized items (Touron & Hertzog, 2004). Thus, older adults may be also less likely to use the memorized visual cues to facilitate the visual search component of the text entry task as younger adults do.

Older Adults and Interaction of Movement and Visual Search

Although age group differences between the interaction of movement and visual search have not been specifically examined, applied studies using tasks that incorporate both components can provide some overall guidance for selection of optimal keyboard shapes for a particular task. One example of this guidance was found by a cognitive models study on Internet navigation wherein older adults were more likely to use serial processing of the different perceptual, cognitive and motor components of most tasks. This study also found significant structural differences in Internet searches between older adults and younger adults (Kurniawan, 2001). These results suggest that even with practice, older adults and younger adults may not perform tasks exactly alike. For instance, older adults may continue to move the cursor in a preferred direction rather than moving in the direction of the shortest movement to make the task easier. This strategy for older adults could support their preference for serial processing and solidify a task plan that is different from younger adults. The current experiment will allow testing of this hypothesis with shape transfer.

Relevance of Age Effects Research

The current study examined whether older adults do improve their performance on this text entry task with practice, and whether improvement is based on experience with the device regardless of shape or whether it is shape-specific. Previous movement research is inconclusive about whether older adults should be expected to improve performance based on movement alone as they restructure movement plans. Previous visual search research suggests that older adults may not change their search strategy to improve overall performance by using memorized cues, though those individuals who use that strategy may still find it easier on one shape than another. The interaction research suggests that less improvement will be found for older adults because the movement and visual search tasks will be performed in serial, but this result has not been tested in a simpler environment like text entry as this study will do.

Usage With Experience

As discussed in each of the sections above, design of controls and displays may differ based on how much time users can be expected to invest in up-front training on a system and receive with usage over time. This final background section summarizes the relevant features of each area that might be affected with this experience.

Task Factors

Given the preference for clear identification of constraints and usage schema, control and display features should be selected to support both intuitive movement and visual search. Users may not even be aware of their movement planning process, but intermittent usage should support some consolidation of the submovements and muscle knowledge to facilitate future performance (Mechsner, 2004). Learning of motor movements and schema can be consolidated even after practice has ended, supporting the use of some spacing of practice sessions in the experiment as representative of the intermittent novice use (Brashers-Krug, Shadmehr, & Bizzi, 1996). In particular, interference during practice on a movement learning study has been found to improve retention and transfer (Magill & Hall, 1990). Research has not examined how shape affordances affect consolidation or retention for a particular device as this study did, however. Research has also not determined how separable the visual affordances need to be to support learning over time. The current study may allow clearer knowledge about the best approach for balancing the two components in the walk-up text entry task under examination.

System Affordances

As described earlier, the availability of affordances drives initial usage in three ways. First, leveraging perceived affordances generally facilitates walk-up success and learning of appropriate movement constraints and planning under intermittent use conditions. This effect on movement will be tested by examining task transfer after a single block of trials, and comparing this to the transfer after additional blocks of trials and an overnight rest. Secondly, feedback provided by the system environment allows some incidental learning, though visual feedback and attention will always be required for getting to exactly the right letter with a rotary knob. This feedback effect will be tested by examining whether performance is the same between shapes by comparing participants who used different layouts that may require different levels of attention. Finally, given the prevalence of novice usage on this device, providing triggers for selection of correct usage schema and natural mapping of the device to the task may be more beneficial than optimization features. The prioritization of these two factors was evaluated by comparing the initial usage period and the early day 2 performance after a day's rest between shapes that differ across these factors.

Age Factors

Both individual task components of text entry and the combination are affected by experience and could be affected by the additional practice provided in this study. First, older adults do not generally seem to consolidate or change their movement strategies over shorter periods of practice as younger adults do, but they may change their strategies with more practice. Second, older adults do not use the memorization search strategy as frequently as younger adults, but they may use this strategy if they have enough practice to learn letter-key mappings. Additionally, declines in visual processing capabilities may make fast discrimination of individual keys for initial target search only possible on shapes with clearer distinction of specific symbols. Finally, an overall difference in balancing multiple tasks in serial vs. a parallel mode preferred by older adults could also suggest different shape preferences, at least for a harder task.

Overview of Study

The purpose of this experiment was to examine the affordances of a virtual keyboard shape as they affect movement, visual search, and the interaction of the two in a text entry task with a rotary controller. This study manipulated keyboard affordances to study the specific cues and triggers provided by a virtual keyboard shape as user guides for the most appropriate schema to use for a particular input device. An additional question for this experiment was the impact of practice on text entry performance. Although previous research has examined the text entry task components individually, particularly for novices and expert users, the interaction of the components and the effects of intermittent usage have not been systematically examined. Transfer conditions were used to assess the nature of the learning that occurred as a function of task practice.

Keyboard Affordances

Two key characteristics of the virtual keyboard were manipulated for the text entry task. First, the shape of the virtual keyboard was varied to promote different movement and visual search characteristics. Second, the keyboard layout of letters, numbers and punctuation marks was varied to promote different visual search strategies and movement planning.

The two shapes chosen for this study shapes are referred to as the *Oval* (a completely-rounded oval display of keys), and *Plus* (a symmetric display of keys based on Oval display but compacting the farthest edges toward the center to create top, left, right, and bottom edges). These two shapes, shown in Figures 3 and 4, were chosen to provide different movement and visual search cues and to represent a range of compatibility features with the rotary knob, screen density, and potential to improve search time with systematic strategies. These were the same shapes as used in the O'Brien et al. study (2005), which investigated movement and visual search individually.

Oval shape. The Oval shape, shown in Figure 3, closely matches the natural motion of the rotary knob. Thus, I expected that this shape would provide participants with high compatibility between the cursor movement and the rotary knob. Because the keys were more spread out than on the Plus shape, however, participants may not be able to visually select as many keys at a time with each fixation (Rayner & Fisher, 1987). Thus, the experiment allowed analysis of whether this shape might be harder to search than more compact shapes like the Plus. The effect of spread might also slow search in a less familiar layout that requires visual search even with practice.

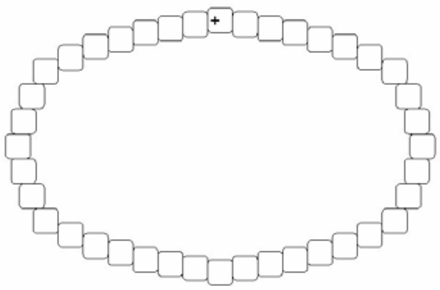

Figure 3. Oval shape used for text entry within experiment.

Plus shape. The Plus shape, shown in Figure 4, combines the compatibility of the rotary controller with rounded shapes with compacted key placement for more effective use of white space. This shape featured a single line of keys on the periphery of the shape, but the keys were placed closer together for higher compactness and character density than the Oval. The symmetric design also featured "anchor points" or visual cues at the corners that might facilitate faster searches once participants learned the layout and selected an effective search strategy. The cues might be particularly more helpful in familiar layouts in which participants know approximately where to search for letters even with little practice.

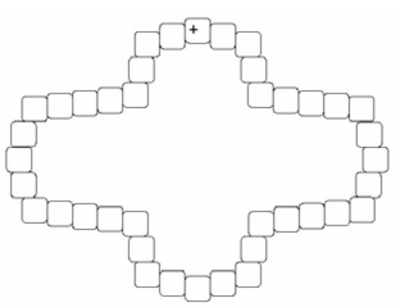

Figure 4. Plus shape used for text entry within experiment.

Hypothesis 1 and 2. Overall, I expected that the Plus shape would be significantly faster than the Oval because the visual search was still more important at the levels of practice evaluated in this experiment. In addition, I expected that the Plus would be less variable in the second day of practice because participants could plan their movements more accurately on this shape. In the O'Brien et al. (2005) study, movement times for younger adults on both shapes were not significantly different, though they were significantly different in the first block of the study. For older adults, however, the shapes were significantly different overall and in both blocks. The Oval shape was both numerically faster and had less variability in both participant groups. It was hypothesized that the corners on the Plus may have initially suggested to users that they plan movements within each Plus segment, but younger adults quickly stopped using this strategy as the feedback from their movements indicated that these corners did not really affect movements. The current experiment allowed more practice for older adults to also adjust their movements to be as smooth as on the Oval. Results of the O'Brien et al. study also suggested that users may have found it easier to memorize the symbols on the Plus corners for faster visual search while the smooth segments of the Oval made discrimination of each symbol more difficult.

Layouts. The two layouts chosen for the experiment are referred to as the *Alphabetic* (completely following the English alphabet) and the *Standard (*QWERTY keyboard standard for typewriters and computer keyboards. In both layouts, symbols were arranged so that the first letter of the layout was presented at the "noon" position on the shape. Only the letter arrangements differed, with numbers and punctuation placed in the same location on both layouts. Punctuation marks were placed directly after the letters, and numbers followed the punctuation marks in sequential order. These are the same layouts as used in O’Brien et al. (2005).

Alphabetic layout. The Alphabetic layout, shown in Figure 5, followed the alphabet exactly, with letters presented in the clockwise order that is naturally afforded by a rotary device (Bradley, 1959). This layout was numerically the fastest layout for participants to search in the O’Brien et al. (2005) study across all shapes. Because participants were likely to be very familiar with this layout, it was likely that search times would improve with practice. Participants could not only map specific letters with specific visual cues as in CM training, but they could also use the well-known order of the alphabet to predict the direction of a target letter from another letter. This might facilitate movement planning by allowing them to combine the movement and search components of the text entry task by starting to move the cursor in the proper direction even before they had specifically identified the location of the target letter.

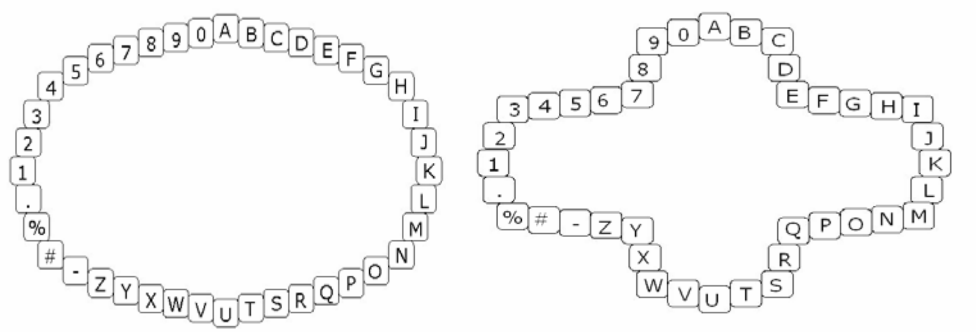

Figure 5. Oval and Plus keyboard shapes with Alphabetic layout.

Standard layout. The Standard layout, shown in Figure 6, of letters used the standard for computers and typewriters in which Q,W,E,R,T, and Y are the first letters displayed across the top letter row on a keyboard (Adler, 1973). Although this layout might be very familiar to typists, it was significantly slower to search on the Oval and Plus shapes than on the rectangular shape that is the most common instance for this layout (O’Brien et al., 2005). The Standard layout was also significantly slower to search than the Alphabetic layout. Thus, it was expected that the Standard layout would to take longer to search on both shapes in the current study. It was also likely that it would be difficult to use without pure memorization in which a specific letter is mapped to a specific cue, increasing the difficulty of transfer from one shape to another. Therefore, I expected that movement planning and overall text entry would be more difficult for this layout.

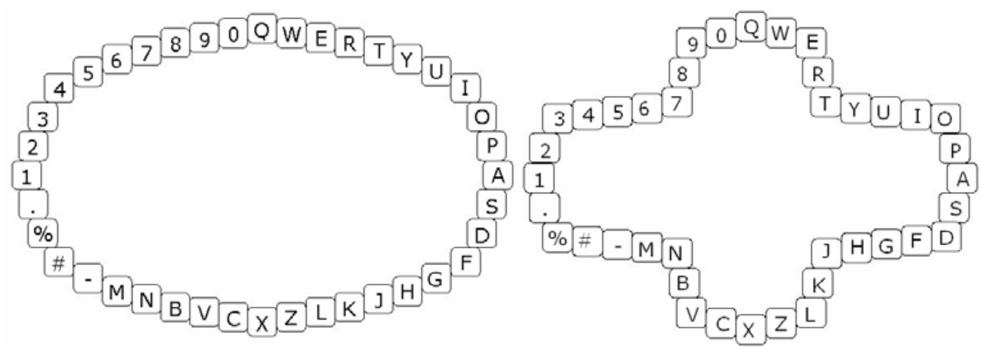

Figure 6. Oval and Plus keyboard shapes with Standard layout.

Hypothesis 3. The Alphabetic layout was expected to be faster than the Standard at every measurement point in this experiment. Based on the fact that the Alphabetic layout is well-learned, participants were expected to quickly focus on the movement aspect of the text entry task. The known ordering of the letters should particularly make searches easy in the clockwise (alphabetical order) direction. The less familiar Standard layout, however, would likely require more cognitive resources to use. Some participants might memorize some of the letters, particularly on the Plus shape where the corners afford easy discrimination. It was unlikely, however, that they could use memorization to find all letters, particularly in a word-entry task with different start and stop points for each letter searched as a word is entered.

Age Effects

Hypothesis 4. The current study supported examination of whether older adults improve their performance on this text entry task with practice, and whether improvement was based on experience with the device regardless of shape or whether it was shape-specific. Previous movement research is inconclusive about whether older adults should be expected to improve performance based on movement alone as they restructure movement plans. For example, the perceived corners of the Plus may facilitate restructuring as users try to find an optimal movement plan afforded by the corners. On the other hand, the compatibility of the Oval might inhibit restructuring because the natural movements may be sufficient for some automatization of movements without the additional overhead of planning the optimal direction. Previous visual search research suggests that older adults may not change their search strategy to improve overall performance by using memorized cues, though those individuals who do may find this to be easier on the Plus shape that affords discrimination more easily than the Oval. Additionally, declines in visual processing capabilities may make fast discrimination of individual keys for initial target search only possible on the Plus shape that has clearer distinction of the letters in the corners. The interaction research from Kurnaiwan (2001) suggests that less improvement will be found for older adults because the movement and visual search tasks will be performed in serial, but this result has not been tested in a simpler environment like text entry (versus the Internet). Thus, older adults were expected to be slower than older adults and to improve less than younger adults, particularly on the Standard layout.

Practice Manipulations

To examine the effects of practice on learning and overall performance, this study was designed with blocks of practice and transfer over two days, similar to the Brown and Carr

(1989) automaticity study. Participants entered words on a virtual keyboard with one shape, but they also transferred to a different shapes or shifted layouts for individual measurement blocks. Transfer effects based on reaction time were the primary dependent variable for this aspect of the experiment. Transfer has been used throughout psychological research to measure learning (for review, see Barnett & Ceci, 2002). For each transfer block, the percentage difference between the mean entry time for the transfer and the practice block divided by the mean entry time for the practice block was calculated. Positive transfer to a novel task (i.e., faster entry time) generally supports the hypothesis that some fundamental or abstract structure was learned prior to transfer. If a negative transfer (i.e., slower entry time) was found, the hypothesis that the participant did not learn the fundamental or abstract components of the previous block(s) or what was learned was not compatible with what they had to do in the new block is generally supported (Schmidt, 1999). No (neutral) transfer indicates that the performance was not disrupted by the transfer, suggesting that the participant did not perceive significant differences between the original and transfer conditions.

Shape Transfers. Effects of switching to a different shape were examined at three points during practice: after little practice, massed practice followed by a day's rest, and additional massed practice. These time periods were selected to represent different levels of experience. The initial block was similar to experience for novice users of a system and for users of walk-up systems with no training. The block following a day's rest represented intermediate experience, similar to intermittent users of a particular system. The final shape transfer after practice represented practice typical of experienced users. Analysis of shape transfer effects facilitated evaluation of learning at each period.

Hypothesis 5. In the early shape transfer (after an initial block of practice), I expected positive transfer in all Alphabetic conditions as participants improved their understanding of the task and showed practice effects. In this early transfer on the Standard layout, Plus participants were expected to show positive transfer due to practice and the perceived easier movements on the Oval shape. For the Oval shape on the Standard layout, however, no transfer was expected as the positive practice effects were matched by slower performance because participants initially perceived the Plus as requiring very different movement planning.

Hypothesis 6. In the intermediate shape transfer (after overnight rest), I expected negative transfer on both Alphabetic conditions as participants were not able to use memorization they had developed as well on the transfer shape as on the original shape. The Oval shape might show lower transfer effects than the Plus because the shape cues were not as salient and useful for memorization. For both Standard conditions, however, I expected very little transfer effects as the initial learning should be more general and less shape-specific.

Hypothesis 7. In the late shape transfer (after five more practice blocks on the same day), I expected negative transfers in both Alphabetic conditions as participants used memory cues that are shape-specific to facilitate the task on the original shape. When the cues were taken away in the transfer shape, performance was disrupted. Transfer was expected to be more negative for the Plus than the Oval due to more salient memory cues on the Plus. For the Standard layout, negative transfer was expected on both shapes though for different reasons. The Plus shape should facilitate incidental learning with more salient memory cues after twelve blocks of practice, so negative transfer was expected on the transfer to the Oval shape as the cues were removed. The Oval shape might allow memorization of the general area and neighboring letters for frequently used letters. Transfer to a shape with different visual cues might disrupt even this memorization, though, so negative transfer was still expected.

Hypothesis 8. In the early shape transfer, older adults were expected to show larger positive transfers in all conditions because the individual visual search and movement tasks showed this effect in previous studies with the same stimuli (O'Brien et al., 2005). Age differences for other transfer points were expected to depend on the level of memorization used by participants for the task. Because older adults may be less likely to use memorization strategies, their transfers were expected to be smaller than younger adults (O'Brien et al., 2005). This age difference was particularly expected to be evident in the Standard layout in which the unlearned letter arrangement made it difficult for older adults to free cognitive resources for incidental learning.

Layout Shift Transfer. The layout shift transfer was designed to assess three aspects of learning: the degree of shape cue-letter mappings, the specificity of the shape transfer effect, and the overall effect of practice. First, negative transfer effects from a layout shift on the primary shape might indicate that individual letters were uniquely mapped to specific aspects of the primary shape. Second, the difference in the effects between the shape transfer and layout shift could indicate the degree to which the effects represented a general change vs. the specific element being changed after sufficient practice. Finally, differences between the initial block and the final layout shift could indicate the degree to which participants reached an optimal level of performance in the primary shape and layout. Comparison of the transfer periods between younger and older adults was also performed to examine preferences for different cues and strategies as well as the differential effects of practice.

Hypothesis 9. Layout shift effects were expected to be negative and similar across shapes, with lower levels of disruption for older adults. For younger adults, memorization of letter locations was no longer applicable for the visual search aspect of the word entry. The shift was expected to be particularly disruptive to the younger adults on the Plus shape who had mapped specific letters to corners and other features of this more unusual shape. On the Oval shape, transfer was might be less affected because participants had only become familiar with a general area of the keyboard for specific letters. For older adults, lower disruption was expected because they were still using visual search to locate letters for each word. The Alphabetic layout, though, was expected to be more impacted than the Standard layout because they may have memorized general spatial areas of the keyboard associated with sections of the alphabet. These were only shifted in this transfer, so the adjustment would be smaller than for younger adults.

Hypothesis 10. Layout shift transfers were expected to be more or equally disruptive than the late shape transfer in this assessment. The Alphabetic Plus condition was expected to have higher negative transfers in the layout shift than the late shape transfer because the optimal strategy was based on specific letter/shape cue mappings. This strategy would be more disrupted by a layout shift in which all cues were changed than a shape transfer wherein the general spatial location of a letter was the same before and after the transfer. In the Alphabetic Oval condition, both transfers were expected to be equally disruptive because the smooth layout promoted learning of the general location and neighboring letters. This knowledge could transfer equally well to a different shape or to a different area of the keyboard. Both Standard conditions were expected to have higher negative transfers in the layout shift because the shift would be hard to discern and participants would start their searching from the top as they had in the beginning of the experiment.

Hypothesis 11. Only younger adults in both Alphabetic conditions were expected to achieve optimal performance levels by the end of task practice. Similar to the consistent display of targets used in Rogers, Fisk, & Hertzog's (1994) search-detection task, the consistent presentation of the keyboard layout in task practice might allow participants to develop a mental image of the keyboard that could consistently improve performance to an optimal level. When the layout was changed sufficiently that participants could not use this mental keyboard, however, this change might disrupt the trend toward automaticity development. Thus, if optimal performance was achieved through practice on a consistent layout in this study, the layout shift might significantly disrupt performance enough that participants would have to re-learn the task as they had in the first experimental block. If memorization were the key to optimal performance, only conditions in which memorization was complete would reach this level. Thus, it is expected that only younger adults on the Alphabetic layout can reach this level. Older adults were not expected to reach optimal performance because they did not memorize individual letters or letter orders. The Standard layout was expected to be too hard for any participants to reach optimal levels of performance before the layout shift, so mean performance on the layout shift block would still be significantly less than the first experimental block.

Overall Hypotheses

There were 11 hypotheses to examine the effects of practice and learning in this word entry study. These are summarized in Table 1.

Table 1
Experimental Hypotheses

Hypothesis	Prediction
1	Plus faster than Oval
2	Less variability in entry times on Plus than Oval
3	Alphabetic faster than Standard
4	Younger faster than Older
5	Alphabetic: positive transfers Standard: no transfer on Oval positive transfer on Plus
6	Alphabetic: negative transfers; more transfer for Plus Standard: no transfer
7	Alphabetic: negative transfers; more transfer for Plus Standard: negative transfers
8	Older: larger transfers in early shape transfer; smaller transfers in other transfers than younger
9	Younger: negative transfers more transfer for Plus Older: negative transfer; more transfer for Alphabetic
10	Alphabetic: Oval: layout shift = shape transfer Plus: layout shift > shape transfer; Standard: layout shift > shape transfer
11	Younger on Alphabetic achieve optimal performance

The practice hypotheses, 1-4, were evaluated by examining only the results of performance on the (original) practice shape. Learning was evaluated through analysis of two different types of transfers. Hypotheses 5-8 were evaluated by examining the differences in shape transfers. Hypotheses 9-11 were evaluated by comparing the layout shift transfer to other blocks and transfers.

METHOD

Participants

The participants were 32 younger adults, ages 18 to 28 years, and 32 older adults, ages 60 to 75 years. (See Tables 2 and 3 for an overview of the participant characteristics.) Younger adult participants were recruited from the Georgia Institute of Technology, and older adults were recruited from a database of community-dwelling Atlanta-area residents. All participants were native English speakers with visual acuity test of 20/40 for far and near vision (corrected or uncorrected). Participants were screened to be right-handed as determined by a handedness questionnaire (Oldfield, 1971). All participants typed at least 9 words per minute as rated through the Mavis Bacon Teaches Typing software program (Cannon, 1999). Participants received either course credit of three hours or monetary compensation of $40 for their participation in this study.

Table 2

Participant Demographics and Ability Test Scores - Alphabetic Layout

	Oval Shape		Plus Shape		
	M	SD	M	SD	t value*
	Younger Adults				
n	8		8		
Age	19.25	1.49	19.88	1.89	-0.74
Choice reaction time [1,2]	359.80	55.24	341.83	42.94	0.73
Shipley vocabulary[3]	31.00	3.16	31.38	4.27	-0.20
Digit-Symbol Substitution[4]	73.63	8.94	75.25	9.53	-0.35
Digit-Symbol Substitution Recall[5]	8.00	1.20	8.63	0.52	-1.36
Reverse Digit Span[6]	6.50	1.51	7.63	2.67	-1.04
Typing Speed[7]	42.00	14.02	44.50	14.65	-0.35
	Older Adults				
n	8		8		
Age	67.50	5.66	69.00	2.62	-0.68
Choice reaction time [1,2]	526.41	92.15	499.38	160.17	0.41
Shipley vocabulary	31.50	3.59	34.13	4.05	-1.37
Digit-Symbol Substitution[4]	53.38	9.35	55.13	8.64	-0.39
Digit-Symbol Substitution Recall[5]	5.13	2.85	4.75	1.28	0.34
Reverse Digit Span[6]	6.63	1.77	7.25	1.16	-0.83
Typing Speed[7]	25.25	12.00	25.13	14.57	0.02

Note: * $p<.05$. Overall age differences (significant at .05) were as follows: Younger adults were faster on choice reaction time and provided more correct answers for digit-symbol substitution, recall, reverse digit span, and typing speed. [1] Correct trials only were included, in ms. [2] Choice reaction time determined by 60-trial test created at the Georgia Institute of Technology using the same rotary controller as in the experiment, in ms. (locally developed). [3] Vocabulary, number correct (Shipley, 1940); [4]Perceptual speed, number correct (Wechsler, 1997); [5]Implicit learning, number correct (Wechsler, 1997); [6]Memory span, number correct (Wechsler, 1997);[7]Adjusted words per minute, measured through Speed Typing test in Mavis Beacon Teaches Typing software (Cannon, 1999).

Table 3
Participant Demographics and Ability Test Scores - Standard Layout

	Oval Shape		Plus Shape		
	M	SD	M	SD	t value*
	Younger Adults				
n	8		8		
Age	19.50	1.85	20.00	1.51	-0.59
Choice reaction time [1,2]	338.34	77.65	373.09	57.51	-1.02
Shipley vocabulary	33.25	1.49	32.38	3.50	0.65
Digit-Symbol Substitution[4]	72.75	10.87	71.13	7.55	0.35
Digit-Symbol Substitution Recall[5]	8.25	1.16	7.88	1.36	0.59
Reverse Digit Span[6]	8.38	1.60	9.25	2.25	-0.90
Typing Speed[7]	51.13	9.98	46.38	14.45	0.77
	Older Adults				
n	8		8		
Age	68.13	3.40	67.75	3.85	0.21
Choice reaction time [1,2]	554.54	188.65	488.17	105.36	0.87
Shipley vocabulary	34.13	2.85	33.63	4.98	0.25
Digit-Symbol Substitution[4]	55.13	9.14	52.63	9.65	0.53
Digit-Symbol Substitution Recall[5]	5.38	2.33	3.00	2.51	1.96
Reverse Digit Span[6]	6.25	1.83	6.88	2.23	-0.61
Typing Speed[7]	20.13	11.66	20.25	8.14	-0.02

Note: *$p<.05$. Overall age differences (significant at .05) were as follows: Younger adults were faster on choice reaction time and provided more correct answers for digit-symbol substitution, recall, reverse digit span, and typing speed. [1] Correct trials only were included, in ms. [2] Choice reaction time determined by 60-trial test created at the Georgia Institute of Technology using the same rotary controller as in the experiment, in ms. (locally developed). [3] Vocabulary, number correct (Shipley, 1940); [4]Perceptual speed, number correct (Wechsler, 1997); [5]Implicit learning, number correct (Wechsler, 1997); [6]Memory span, number correct (Wechsler, 1997);[7]Adjusted words per minute, measured through Speed Typing test in Mavis Beacon Teaches Typing software (Cannon, 1999).

Apparatus/Materials

The experiment was conducted in a quiet office using an IBM-compatible 600 MHz Pentium/3 desktop computer running under Microsoft Windows 2000. A pink noise generator was used to mask outside noise. The computer program was developed in Visual Basic, Studio Version 6.0 at the Human Factors and Aging Laboratory at the Georgia Institute of Technology for presenting stimuli and recording results of this experiment. The software program measured the search times and accuracy for each trial using the system clock. All measurements were recorded automatically by the program into a separate data file for later analysis.

The system included a 17" color monitor, a standard mouse and keyboard. The monitor was configured to display 1024 x 768 pixels. The software program presented each virtual keyboard shape in a 5x7 display area with forty ½ inch buttons. This button size was determined to fit the keys best on the Oval shape, and it was used in both shapes. Letters, numbers, and punctuation marks on the keyboard layouts were presented in Georgia 18 point font. All words were presented in Georgia 24 point font.

The rotary controller is a hardware input device that was customized for Deere & Company products and services. The controller includes eight customizable buttons and a rotary knob with 20 knob clicks for a 180-degree rotation. Buttons were programmed for specific functions as described in the procedure for the experiment. Buttons were labeled as shown in Figure 2. The top buttons were color-coded with a blue dot sticker on the left button and a yellow dot sticker on the right button. One button on the right side of the second row was coded with a metallic star sticker. The bottom left button was coded with a red triangle (arrow) sticker.

The cursor moved clockwise and counterclockwise along the key spaces as the knob was rotated. Participants were able to hear and feel the clicks as they rotated the knob. Letters were chosen using the “item-selection” method, whereby the rotation of the knob sequentially moves the cursor through the symbol set with a single symbol highlighted at a time. When the desired symbol is highlighted, the user pushed the blue button on the controller to select it (Bellman & MacKenzie, 1998).

Ability tests. The ability measures were the Shipley Institute of Living vocabulary scale (Shipley, 1940), the Reverse Digit Span test (Wechsler, 1997), the Digit Symbol Substitution test (Wechsler), and choice reaction time test (developed locally). Participants were also given a typing test to test their knowledge of the standard QWERTY keyboard using the speed test within the Mavis Bacon teaches typing software program (Cannon, 1999).

Stimuli. A total of 255 four-, five-, and six-letter words were selected from the eLexicon database of word norms (Balota et al., 2002) as stimuli. This database uses the HAL corpus of approximately 131 million words from about 3000 Usenet newsgroups, providing frequency counts for the number of times that 40,481 English words appeared in this corpus (Burgess & Livesay, 1998). For each letter length, the 85 most frequent words were extracted for potential inclusion on the list. Proper nouns, words with repeated, consecutive letters, and homonyms were discarded and replaced by a word with the next highest frequency. The resulting three lists of four-, five-, and six-letter words were combined and quasi-randomly placed in a single list. I then visually inspected the list to ensure that no more than three words of the same length were consecutively placed on the list. Finally, manual movement of words was completed to ensure that words of close semantic or spelling relation were not in close proximity.

Each word was used once for each participant. To eliminate potential sequence and motoric knowledge effects found by Brown and Carr (1989), Wulf and Schmidt (1997) and Fendrich, Healy, and Bourne (1991), four pseudo-random word orders of the list were created (shown in Appendix A). Visual inspection of the resulting lists and manual movement of words was repeated as described above. These word orders were assigned to participants in different shape and layout conditions to provide counterbalancing (as shown in Appendix B).

Design

The experiment used a 2x2x2 design for the two different keyboard shapes, two different symbol layouts, and two participant groups of younger and older adults. The design was completely counterbalanced for all combinations of keyboard shapes and layouts, with four different word orders assigned to equal numbers of the shape/layout conditions. Shape and layouts were between-participant variables. Age was a grouping variable. Thus, there were eight participants in each shape/layout condition for each age group. Participants were assigned to a shape/layout condition in the order in which they arrived for the experiment. The primary dependent variable was word entry time, though accuracy was also measured and checked against word entry time to confirm that participants did not trade word entry time for accuracy.

Procedure

Participants performed seventeen blocks of trials, with 15 words entered in each block, as shown in Table 4. Twelve blocks were practice blocks (P), wherein participants used the initial shape assigned to them for the text entry task. These blocks were used to assess general effects of experience.

Table 4
Experimental session design, showing block order, block types, number of blocks for each type, and word count for each block.

	Day 1				**Day 2**							**Totals**
Block type	practice	**shape transfer**	practice		practice	**shape transfer**	practice	**shape transfer**	baseline	**layout shift**		
Block label	P1	ST1	P2-P6		P7	ST2	P8-P12	ST3	B1	LS1		
Number of words in block	15	15	75		15	15	75	15	15	15		**255**
Number of moves in block	75	75	375		75	75	375	75	75	75		**1275**

In shape transfer (ST) blocks 1-3, participants performed the same text entry task but used the alternative shape keyboard. These shape transfer blocks were completed after practice blocks 1, 7, and 12. After shape transfer block 3, participants returned to the assigned shape for one baseline block. In the layout shift (LS) block, participants completed the same text entry task on their original virtual keyboard shape but the layout was shifted. Within each shift, each letter was moved clockwise seven spaces within the alphabetic section of the layout. Numbers and punctuation marks remained in the same locations. These shifts are shown in Figure 7 for the Alphabetic layout and Figure 8 for the Standard layout.

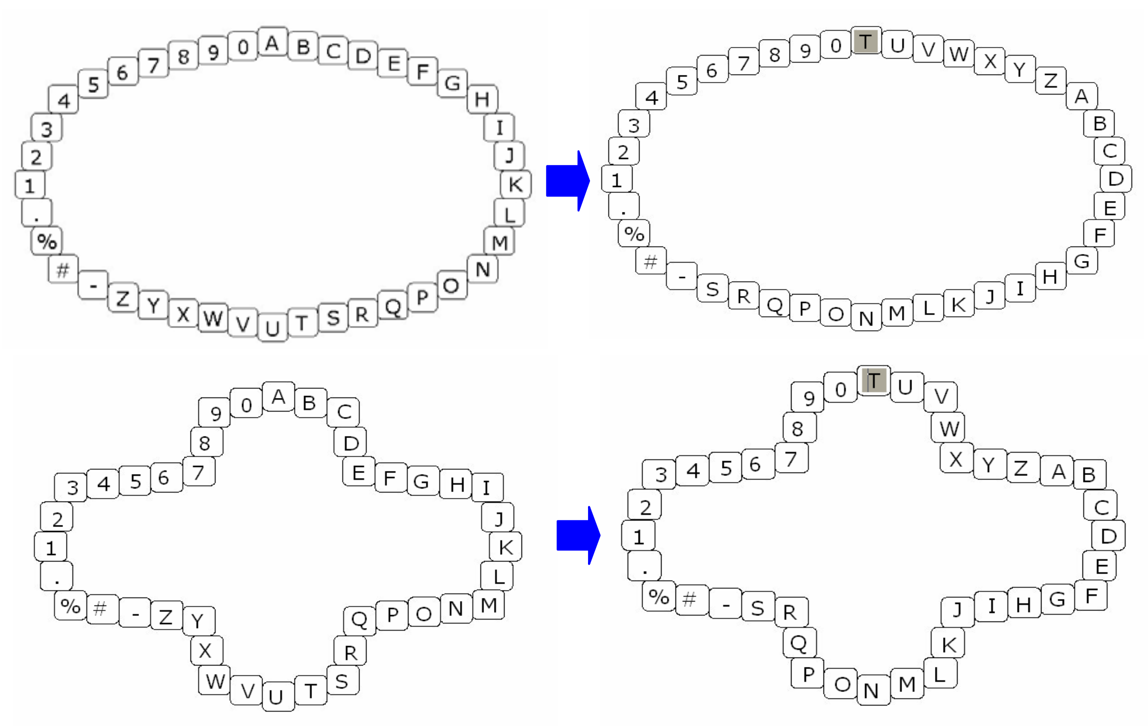

Figure 7. Oval and Plus keyboard shapes with (left) Original and (right) Shifted Alphabetic layout.

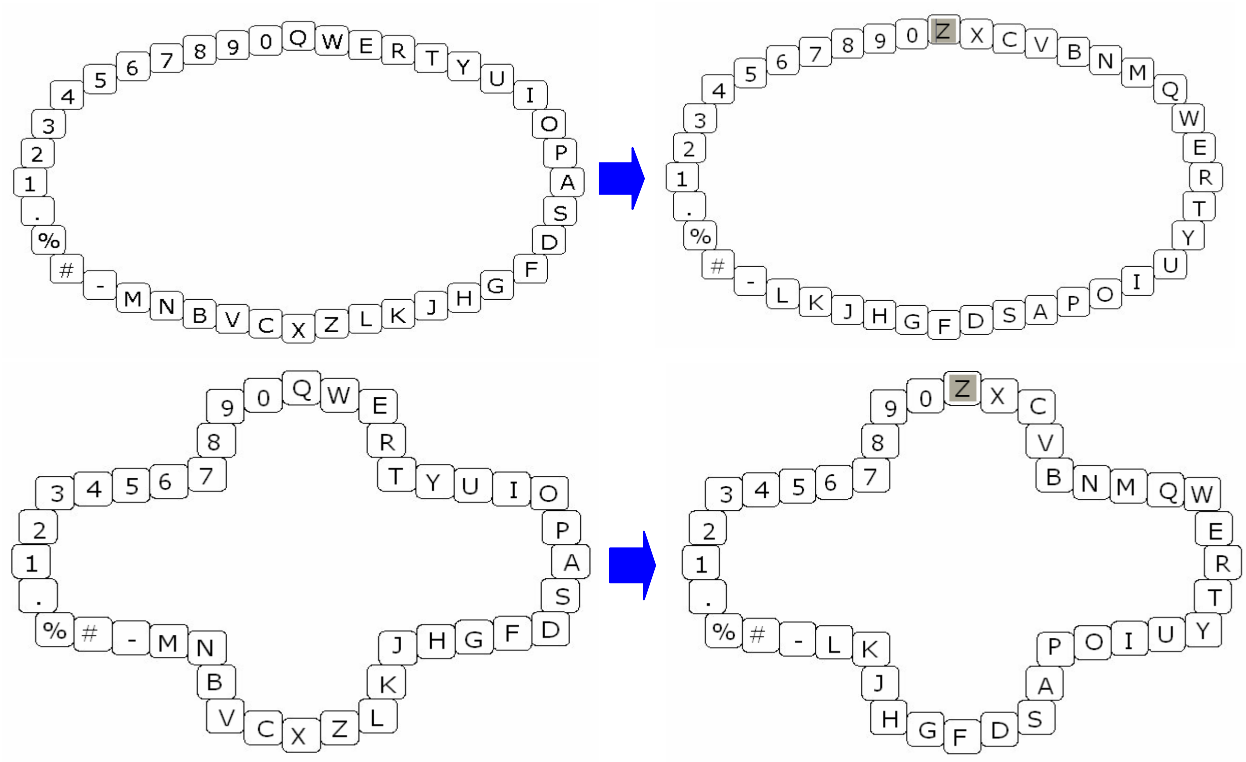

Figure 8. Oval and Plus keyboard shapes with (left) Original and (right) Shifted Standard layout.

Participants were scheduled over a two-day period, with no more than 32 hours between the sessions. Participants were first given a detailed description of the study and had their questions answered about this description and their participant rights. Participants then provided informed consent, and were then screened for visual acuity, right-handedness, and typing ability. They were then given the choice reaction time test, which additionally provided participants with experience with the push buttons on the rotary controller. Instructions on the experiment were then provided, along with three words entered by the experimenter and three practice words entered by the participant. They were instructed to search quickly but accurately with a target of 90%; errors were not corrected. After remaining questions were answered, participants started the experimental trials.

In each trial, participants were presented with a word to enter. They were allowed to study the word for up to 20 seconds, or press the arrow key on the controller to start searching when they were ready. They were then presented with a '+' character for .5 second focus before the keyboard appeared. After the participant moved the cursor to the desired letter, the participant selected the blue dot button. When they finished entering a word, they selected the arrow button. The trial timed out if the participant had not finished entering a letter within twenty seconds. After each word, the computer provided accuracy information and word entry time for correct words. Participants were allowed to take a break in the middle of a block by pressing the star key after entering a word, and a mandatory ninety-second break was enforced after every three blocks.

At the end of each block, participants were given block accuracy and average word entry time in ms. A timeout was scored as incorrect for the purpose of calculating accuracy and average block entry time. If the participant's accuracy was below 85%, participants were asked to be more accurate. If accuracy was above 95%, participants were asked to work more quickly. No additional guidance was provided for participants whose accuracy was within the 90-95% goal. The experimenter encouraged participants to look around the room to relax their eyes and to shake their wrists to reduce fatigue during breaks. At the end of the seventh block on Day 1, participants were given the Shipley Institute of Living vocabulary scale (Shipley, 1940). They were also given demographics and technology experience questionnaires (shown in Appendix C) to complete before Day 2.

At the beginning of Day 2, participants were reminded of the study purpose and their participant rights. They were then given the Reverse Digit Span test (Wechsler, 1997). Then, they were reminded of the task instructions and given two training trials before experimental trials began. At the end of all experimental blocks, participants were asked if they used any strategies to complete the tasks either initially or as the trials progressed. The Digit Symbol Substitution test (Wechsler, 1997), an exit interview, and debrief were then given to all participants. Finally, participants were compensated as appropriate for their age group.

RESULTS

Data Analysis

The computer program stored all movements for each participant in a separate file. In addition to the raw listing of each movement, summary rows were created for each letter and each word with totals for number of movements and movement time, start position, target position, end position, and correct selection of the trial. An error was recorded if the participant selected the blue dot when the cursor was not on the target position.

Data from participants were analyzed to confirm that participants met the target accuracy requirements and fell within standard normal distribution as described below. For each block, day, and word length, data for each participant were then analyzed for outliers and extreme values by determining the mean and standard deviation of correct trials. Outlier ranges for each of these fields were calculated as the mean plus or minus a value of 1.5 times the standard deviation. Extreme value ranges for each of these fields were calculated as the mean plus or minus a value of 1.5 times the standard deviation. Individual trials were then eliminated from the participant's data if they met two criteria. First, word entry time fell outside the extreme value range for the overall block, the day, or the word length. Second, word entry time fell outside of the outlier range for that participant on the other two fields. Participants' performances were then reviewed to confirm that remaining correct data available for analysis was at least 60% for each block. In addition I noted that no more than one block was lower than 80% for each participant which confirmed that participants were trying to keep their accuracy in the target 85-95% range. After this review, no participants were excluded because the totals fell outside of criterion according to this analysis process.

To determine if any participant fell outside of normal distribution for their experimental condition, means and standard deviations for each age group and participant condition were then calculated. An outlier range was determined as the mean plus or minus two times the standard deviation. Participants were highlighted if their data were outside of this outlier range for a block, and they were eliminated if their data were highlighted for more than three blocks. One older adult and one younger adult were eliminated because they represented outliers for their condition according to this analysis. Note that eleven other participants were excluded for other procedural and screening reasons as described in Appendix D. If a participant's data were excluded for any reason, this participant was replaced with another participant from the same age group meeting the criteria described in the Participants section.

Statistical Results

Analysis of results is presented in two sections: practice and learning. Accuracy was high overall and quite similar across Shape and Layout as shown in Table 5. A repeated measures ANOVA for accuracy revealed a main effect of Age ($F(1,56) = 6.15$, $p < .05$, $\eta^2 = .10$), but mean accuracy for both (Younger Adults $M = .95$, $SD = .03$, Older Adults $M = .96$, $SD = .02$) was at or near the 95% top boundary for target accuracy which indicates that participants were not trading entry time for accuracy. Thus, the analysis focuses on word entry time. The full ANOVA results for the accuracy data can be found in Appendix E.

Table 5
Accuracy results (proportion correct) for all shape and grouping conditions, separated by block type

	Layout	Mean: Alphabetic		Mean: Standard		Standard Deviation: Alphabetic		Standard Deviation: Standard	
	Shape	Oval	Plus	Oval	Plus	Oval	Plus	Oval	Plus
Younger Adults	Practice	0.96	0.94	0.95	0.96	0.02	0.02	0.03	0.03
	Shape transfer	0.97	0.94	0.95	0.94	0.04	0.03	0.05	0.06
	Baseline	0.94	0.93	0.95	0.93	0.06	0.06	0.06	0.07
	Layout Shift	0.94	0.95	0.93	0.93	0.05	0.07	0.05	0.03
	Overall	0.96	0.94	0.95	0.95	0.02	0.02	0.03	0.03
Older Adults	Practice	0.96	0.97	0.97	0.97	0.03	0.02	0.02	0.01
	Shape transfer	0.96	0.95	0.97	0.96	0.04	0.03	0.04	0.03
	Baseline	0.95	0.97	0.95	0.93	0.07	0.04	0.05	0.03
	Layout Shift	0.98	0.97	0.97	0.95	0.03	0.04	0.05	0.05
	Overall	0.96	0.97	0.97	0.96	0.03	0.02	0.02	0.01

Practice

Practice measurement periods were created from the mean word entry time of each two consecutive practice blocks (i.e., blocks P1 and P2 became period 1, blocks P3 and P4 became period 2, etc.) to form six practice periods. These practice periods were used for all analysis of practice. Gains were calculated as the difference between the mean of period 6 and the mean of period 1.

To determine whether shape, layout, age, or practice influenced word entry time, I conducted a repeated measures ANOVA. The results of the Shape x Age x Layout x Practice ANOVA are reported in Table 6, starting with a significant four-way interaction of all factors.

Table 6

Practice ANOVA Results for entry time (Shape x Age x Layout x (Practice))

Source	*df*	*F*	*p*	ηp^2
		Between participants		
Shape (S)	1	0.51	0.480	0.01
Age (A)	1	237.94	*0.001*	0.81
Layout (L)	1	21.93	*0.001*	0.28
S x A	1	1.44	0.240	0.03
S x L	1	0.62	0.430	0.01
A x L	1	0.91	0.350	0.02
S x A x L	1	0.18	0.670	0
error	56	(1.41E+06)		
		Within participants		
Practice (P)	5	424.58	*0.001*	0.88
P x S	5	1.19	0.320	0.02
P x A	5	39.38	*0.001*	0.41
P x S x A	5	0.44	0.820	0.01
P x S x L	5	4.99	*0.001*	0.08
P x A x L	5	2.26	0.050	0.04
P x S x A x L	5	3.59	*0.001*	0.06
error	280	(1.94E+05)		

Note: Italics indicate significant *p* values ($p<.05$)

As expected, these results show a main effect of age, layout, and practice. The gain for older adults (*M* = 4249.23, *SD* = 1390.05) was greater than for younger adults (*M* = 2362.43, *SD* = 731.21). The gain on Standard layouts (*M* = 3967.04, *SD* = 1575.38) was greater than on Alphabetic layouts (*M* = 2644.62, *SD* = 959.12), possibly because of the higher difficulty of the layout in the beginning that required more learning. All participants improved with practice (period 6 *M* = 7039.40 < period 1 *M* = 10345.07). All of these have medium (layout) to large (age and practice) effect sizes as shown by the partial eta squared (ηp^2) values.

The most interesting effects related to the experimental hypotheses are reflected in the three-way interactions of practice by shape by layout and of practice by age by layout. First,

Figure 9 shows the three-way interaction of practice by shape by layout with Alphabetic on the left graph and Standard on the right graph.

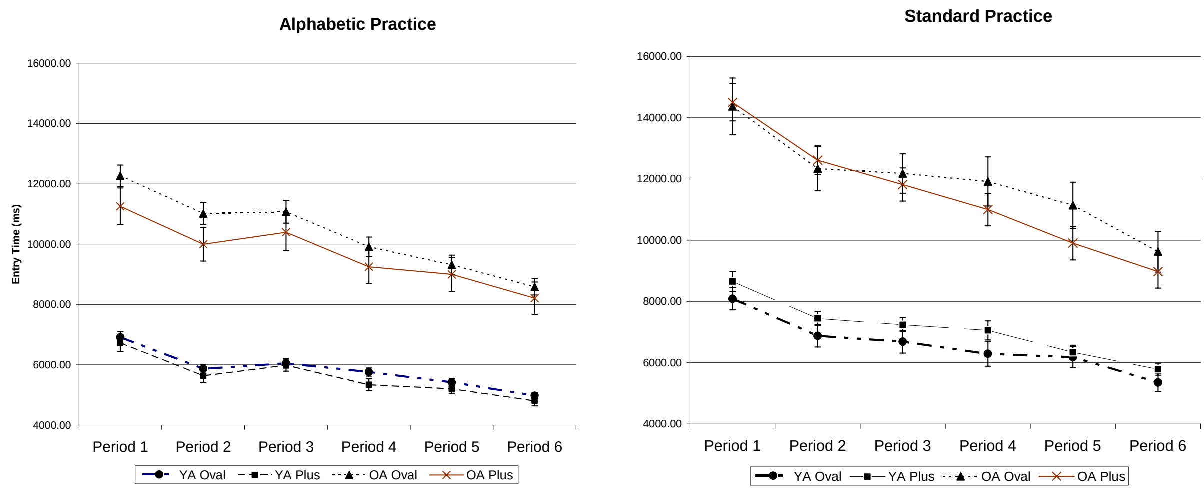

Figure 9. Mean word entry time by age (YA = younger adult, OA = older adult) and shape across practice (X-axis shows practice periods), with Alphabetic layout on the left and Standard layout on the right. Y-axis represents word entry time in ms. Bars represent standard error.

This figure shows that Plus improved more for both age groups in the Standard layout, but not in the Alphabetic layout. Note the marginal effect size (ηp^2 =.08) for this interaction. Neither layout had a significant practice by age by shape interaction (*p*'s > .05). However, the Standard layout had a significant interaction of practice by shape in which the Oval was faster on day 1 though Plus was faster on day 2. This interaction was not significant for the Alphabetic layout (*p* =.15).

Given the 4-way interaction of shape, layout, age, and practice on entry time, a follow-up ANOVA was performed to examine the effects of practice by layout by shape interaction for each age group. For older adults, the interaction was significant ($p < .001$), but it was not significant for younger adults (*p* =.17). Table 7 shows these performance gains, whereby both shapes improved equally for older adults in the Alphabetic layout, but Plus improves more for older adults in the Standard layout.

Table 7

Performance Gains over Practice (word entry time in ms)

		Mean				Std. Deviation			
	Layout	**Alphabetic**		**Standard**		**Alphabetic**		**Standard**	
	Shape	**Oval**	**Plus**	**Oval**	**Plus**	**Oval**	**Plus**	**Oval**	**Plus**
Younger		1934.80	1919.43	2733.46	2862.04	445.63	512.03	724.37	711.66
Older		3678.16	3046.08	4743.35	5529.31	817.22	602.82	1159.86	1414.84

To analyze the variability in word entry time across each period, I examined the average intra-individual variability for participants in each practice group. This variability was calculated for each participant by finding the standard deviation for each practice period. A repeated measures ANOVA for shape, layout, age, and practice was then performed against this variability. The ANOVA (reported in Table 8) showed no significant four-way or three-way interactions (all *p's* > .08).

Table 8

Practice ANOVA Results for standard deviation (Shape x Age x Layout x (Practice))

Source	*df*	*F*	*p*	ηp^2
		Between participants		
Shape (S)	1	0.08	0.780	0.001
Age (A)	1	142.50	*0.001*	0.72
Layout (L)	1	34.39	*0.001*	0.38
S x A	1	0.16	0.690	0.003
S x L	1	1.73	0.194	0.03
A x L	1	0.94	0.338	0.02
S x A x L	1	0.24	0.625	0.004
error	56	(6.42E+05)		
		Within participants		
Practice (P)	5	91.78	*0.001*	0.62
P x S	5	1.81	0.111	0.03
P x A	5	8.03	*0.001*	0.13
P x S x A	5	0.69	0.630	0.012
P x S x L	5	1.94	0.088	0.03
P x A x L	5	0.95	0.450	0.02
P x S x A x L	5	1.08	0.370	0.02
error	280	(8.72E+.04)		

Note: Italics indicate significant *p* values (*p*<.05)

I conducted a post-hoc analysis of the practice by shape by layout interaction (p =.088) with a repeated measures ANOVA on variability for each period. Results showed that the layout by shape interaction was only significant for period 4 ($F(1,56) = 4.534$, $p < .05$, $\eta^2 = .08$). In this period, which occurs early in day 2, standard deviations for Oval were significantly larger than for Plus on the Alphabetic layout as shown in Table 9. This lower variability suggests that participants on the Plus were more accurate in finding the letters and moving to the letters than those participants on the Oval.

Table 9
Standard Deviations for Period 4 by Age and Layout (in ms)

	Mean		**Std. Deviation**	
	Oval	**Plus**	**Oval**	**Plus**
Alphabetic	2069.36	1795.29	504.31	536.26
Standard	2444.47	2599.01	780.43	659.59

The overall ANOVA results also support the findings shown in Table 10, namely that older adults were more variable than younger adults (significant practice x age interaction) and that the Standard layout was more variable than the Alphabetic layout (significant practice by layout interaction).

Table 10
Standard Deviations for each Period, by Age and Layout (in ms)

	Age Group				**Layout**			
	Mean		**Std. Deviation**		**Mean**		**Std. Deviation**	
	Younger	**Older**	**Younger**	**Older**	**Alpha**	**Standard**	**Alpha**	**Standard**
Period 1	1906.46	3190.49	329.23	804.09	2328.41	2768.55	791.14	938.10
Period 2	1606.39	2685.28	322.43	485.32	1950.59	2341.08	635.21	676.82
Period 3	1527.73	2543.35	363.64	612.93	1707.97	2363.11	514.83	744.12
Period 4	1754.13	2699.94	426.31	573.46	1932.33	2521.74	530.66	715.12
Period 5	1363.73	2237.79	323.54	584.74	1572.37	2029.15	500.11	695.06
Period 6	1197.32	1856.43	265.27	471.49	1354.06	1699.69	453.05	499.99

Key Practice Periods. Overall practice results at the novice, intermediate, and practiced user levels are summarized in Table 11. These results show that where there was a layout effect, the Alphabetic layout is faster except for the Oval shape at period 4. The only shape effect was found in this interaction for younger adults in period 4, whereby Plus was faster for Alphabetic but Oval was faster for Standard. This interaction suggests that different strategies may have been used by participants at this period for different layouts. Note that period 4 was also the only practice period in which the Plus shape was significantly less variable than the Oval shape on the Alphabetic layout. This period was after an overnight break, so some information may have been lost and other information may have been consolidated. As found in the Magill and Hall (1990) study, aspects of the Plus shape used for the text entry task may have been retained better overnight for the Alphabetic layout. On the Standard layout, however, memorization of specific letter locations may have been less likely but the movement planning may have been learned better on the Oval shape. Analysis of the transfer results, presented next in this report, will help clarify this and other potential learning.

Table 11

Summary of Practice Performance by Age Group

User Level	**Novice**	**Intermediate**	**Practiced**
Practice Period	**Period 1**	**Period 4**	**Period 6**
Older Adults	Alpha faster (p=.001) No shape effect (p=.51)	Alpha faster (p=.03) No shape effect (p=.36)	No layout effect (p=.096) No shape effect (p=.33)
Younger Adults	Alpha faster (p=.001) No shape effect (p=.54)	Significant LxS interaction: p=.046: for Alpha, Plus is faster; for Std, Oval is faster. Alpha faster (p=.001) No shape effect (p=.55)	Alpha faster (p=.003) No shape effect (p=.53)

Note: Significance based on p values <.05. Alpha = Alphabetic layout; Std = Standard layout; Younger = Younger Adults; Older = Older Adults.

Practice Summary. The results show partial support for the four hypotheses regarding practice effects. The prediction of a shape effect was only supported in period 4 for younger adults, and that effect was part of an interaction. The Plus was only less variable than the Oval on the Alphabetic layout in period 4. The performance gain on the Standard layout was higher than on the Alphabetic layout, but Alphabetic layout was still faster as expected. Performance gain for older adults was higher than for younger adults, but younger adults were faster as expected. The differences from predictions will be analyzed in the learning section with the results from the transfers.

Learning

Learning effects were evaluated by examining the results of the three shape transfers and one layout shift. Results were measured with transfer scores and proportion scores for each participant. Transfer scores were calculated first by subtracting the mean entry time of the transfer block from the mean entry time of the practice block just prior to the transfer. The resulting transfer score was then divided by the mean of the practice block to produce a proportion score. Analysis of learning effects focused on proportion scores to minimize the general practice effects described above, whereby younger adults were significantly faster than older adults and the Alphabetic layout was significantly faster than the Standard layout. All transfer and proportion scores are reported with negative scores indicating improvement (positive transfer).

To determine whether shape, layout, or age affected what participants learned during their word entry practice, I conducted a repeated measures ANOVA on proportion scores for the three shape transfers. Results of the Shape by Age x Layout x Transfer are reported in Table 12. Specific means and standard deviations for the transfers are reported in the individual section for each transfer point.

Table 12
Shape Transfer ANOVA Results (Shape x Age x Layout x (Transfer))

Source	*df*	*F*	*p*	ηp^2
	Between participants			
Shape (S)	1	39.33	*0.001*	0.41
Age (A)	1	0.52	0.47	0.01
Layout (L)	1	9.01	*0.004*	0.14
S x A	1	0.15	0.70	0.00
S x L	1	0.84	0.36	0.01
A x L	1	0.19	0.66	0.00
error	56			
	Within participants			
Transfer (T)	2	119.14	*0.001*	0.68
T x S	2	4.04	*0.02*	0.07
T x A	2	0.15	0.86	0.00
T x L	2	2.83	0.06	0.05
T x S x A	2	0.17	0.84	0.00
T x S x L	2	1.48	0.23	0.03
T x A x L	2	0.53	0.59	0.01
T x S x A x L	2	0.04	0.96	0.00
error	112			

Note: Italics indicate significant *p* values (p<.05)

Overall, these results show that all of these factors have some effect on learning, though the level and direction of the effects vary by transfer point. There was one significant interaction between transfer and shape (p < .01), with a more positive transfer for Plus in the early and mid transfers but a more negative transfer for Oval. Main effects were found for layout (p < .01) whereby the Alphabetic layout was more disrupted than the Standard layout (p < .001), transfer point (p < .001) whereby transfer scores are significantly different at each point, and shape (p < .001) whereby Plus has an overall positive transfer though Oval has an overall negative transfer. These effects will be described more fully in analysis at each transfer point, with full ANOVAs for these analyses in Appendix E. No significant age difference surfaced in the shape transfer analysis, so hypothesis 8 was not supported.

The early transfer designates transfer from the original to the alternate shape after one block of practice, representing the typical novice user experience. All transfers were positive as was predicted given that participants have only entered fifteen words on each shape. Thus, the task practice likely accounts for most of the positive transfer. This explanation was tested with a univariate ANOVA for shape, age, and layout effects on the proportion score. Results showed significant effects only for shape ($F(1,56) = 4.43$, $p<.05$, $\eta^2=.07$). As shown in Table 13, transfer was less negative for Oval than for the Plus shape in each age and layout condition. The most likely explanation for this difference is that participants practicing on the Oval learned more shape-specific components of the task, and thus the different affordances on the Plus interfered with the previous learning. Hypothesis 5 was partially supported with the overall positive transfer effect, though the expected neutral transfer for Oval on Standard was not found.

Table 13
Proportion Scores for Early Transfer, Means and Standard Deviations ((ST1-P1)/P1)

	Mean				Standard Deviation			
	Younger		Older		Younger		Older	
	Alphabetic	Standard	Alphabetic	Standard	Alphabetic	Standard	Alphabetic	Standard
Oval	-0.12	-0.11	-0.07	-0.12	0.03	0.09	0.09	0.05
Plus	-0.14	-0.16	-0.12	-0.15	0.09	0.06	0.06	0.07

Evaluation of the middle and late shape transfers provided a method for determining whether the pattern for positive transfer for Plus but neutral transfer for Oval continued or whether changes were found that might indicate consolidation of the task components or changes in strategy. To emphasize the comparative nature of this evaluation, these transfers areboth presented in Figure 10. In this figure, the left graph shows the middle shape transfer which occurs after an overnight rest and one block of practice on the original shape. The right graph shows the late transfer, occurring on the second day after five blocks of practice on the original shape.

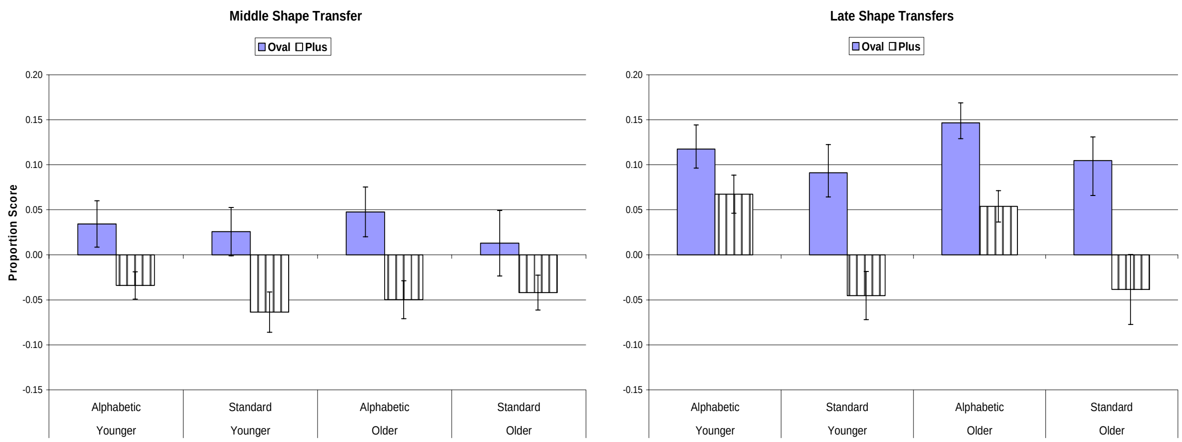

Figure 10. Proportion scores for middle and late shape transfers across age and layout, with the middle transfers on the left and late transfers on the right. Y-axis represents proportion scores, with the difference between block means (transfer – practice) divided by the practice block mean. Scores for the Oval shape are shown in solid shading, and scores for the Plus shape are shown with checkered shading. Negative values indicate positive transfer (faster entry time after transfer), and positive values indicate negative transfer (disruption with transfer). Bars represent standard error.

The middle transfer represents an intermediate level of practice in which participants have completed only one practice block on the original shape after an overnight rest. Results of a univariate ANOVA for shape, age, and layout effects on proportion scores showed only a main effect of shape ($F(1,56) = 19.14$, $p < .001$, $\eta^2 = .26$). Transfer from the Oval to the Plus at this point was not significantly different than 0 ($t(31) = 1.63$, $p = .113$), indicating that the learning from the Oval shape practice was not shape-specific. The transfer from Plus to Oval (M = -398.06 ms, SD = 478.24 ms), however, was positive as it had been in the early transfer. As opposed to hypothesis 6 that disruption would be different by layout, disruption in the middle period was different only by shape with positive transfers for Plus and no transfer for Oval.

These results on the middle shape transfer point (between practice blocks P7 and P8) can also help analyze the earlier findings of the shape by layout interaction in practice at period 4, whereby Plus was faster for the Alphabetic layout but Oval was faster for the Standard layout. Together, these results suggest that the easier (Alphabetic) layout allows generalizable learning but the Standard layout only allows shape-specific learning. Because the Alphabetic layout was easier/more well-learned, participants may have had sufficient free cognitive resources to learn several aspects of the overall task better. In particular, Magill and Hall's (1990) study suggests that contextual interference improves motor skill learning as tested in retention and transfer performance. The corners/segments of the Plus may have provided variety or interference that improved learning the movement aspects of the task for better transfer to the Oval. This learning may also have reduced variability in performance on the Plus itself. Because the Standard layout was harder, however, even younger adults may have not had sufficient free cognitive resources to learn both visual search and movement aspects of the task. The visual search (layout) component was hard to learn, but the Oval shape was easier in the movement-only task (O'Brien et al.). Thus, participants may have chosen to learn the movement components. The movement learnings may have been retained overnight, contributing to higher performance early on Day 2 on the Oval itself and at least neutral performance on the Plus, a less-practiced shape with different cues.

By the late transfer, representing an experienced user level from twelve blocks of practice on two days, these effects have changed. Results of a univariate ANOVA for shape, age, and layout effects on proportion scores showed main effects of shape ($F(1,56) = 30.47$, $p < .001$, $\eta^2 = .35$) and layout ($F(1,56) = 12.72$, $p < .01$, $\eta^2 = .19$). Transfer from the Oval to the Plus was now significantly different than 0 ($t(31) = 7.51$, $p < .001$) and negative ($M = 814.39$ ms, $SD = 613.21$ ms), suggesting that learning after additional practice had become shape-specific. The transfer from the Plus to the Oval, however, was not significantly different than 0 ($t(31) = .083$, $p = .93$), indicating an overall lack of disruption in the move to a new shape. This result was surprising given the unique corners on the Plus that were expected to facilitate memorization and visual search, especially with the amount of practice that participants had now received. The significant layout effect found in the ANOVA, whereby the Alphabetic layout (M =635.52 ms, SD=523.24 ms) was significantly more disrupted in the late transfer than the Standard layout (M = 188.92 ms, SD = 158.46 ms), provided an avenue for further investigation of this result.

To investigate specifically the effects of shape and layout on the changes in disruption between the middle and late periods, a repeated measures ANOVA of shape, age, layout, and transfer point was performed on the proportion scores for the both periods. After the ANOVA revealed a transfer point by layout interaction ($F(1,56) =5.07$, $p<.05$, η^2=.08), one-sample T-tests were performed separately on the proportion scores for each transfer point by layout. These T-tests showed that the neutral transfer for the Oval found for the middle transfer held for both layouts (both p's >.05), confirming the earlier result that learning at the intermediate period is not shape-specific for the Oval. Both layouts independently had significantly positive transfers for Plus at the middle period (Alphabetic ($t(15)$ =-2.94 , p < .05), Standard ($t(15)$ =.-3.64 , p < .01)), also confirming the generalizable learning on the Plus at this point. The lack of transfer for Plus in the late transfer, however, only held in the Standard layout (p= 087). For the Alphabetic layout, the late transfer on the Plus (M = 370.43 ms, SD=329.45 ms) was significantly negative and different than 0 ($t(15)$ =.4.50 , p < .001). Thus, shape-specific affordances of the Plus were learned with more experience on the Alphabetic layout but not on the Standard layout. Additional practice on the Plus after the intermediate transfer may have allowed Alphabetic participants to memorize specific letter/shape cue mappings and create a mental image of the keyboard to improve their performance. This level of memorization would have been much more difficult on the Standard layout. Overall, hypothesis 7 was supported in the Alphabetic layout but not for the Standard layout.

These analyses were repeated for early, middle, and late difference scores to evaluate any differences that may have resulted from the linear transformation of difference scores into proportion scores. The univariate ANOVA results are listed in Appendix F. All results show similar patterns to the results of analysis for proportion scores with the following exceptions. For the early transfer, analysis of the difference scores revealed significant effects of age ($F(1,56) = 7.07$, $p<.05$, $\eta^2=.11$) and layout ($F(1,56) = 8.28$, $p<.05$, $\eta^2=.13$), reflecting the higher effects of task practice in both areas expected. The significant effect of shape found in the proportion scores was not found in the difference score analysis ($p=.09$), supporting the previous discussion about this shape effect that the larger positive transfer for Plus was small. For late transfer, a significant shape by age ($F(1,56) = 4.66$, $p<.05$, $\eta^2=.08$) was found in addition to the significant shape and layout interactions. Specifically, there were no age differences on the Plus shape but older adults were significantly more disrupted than younger adults on the Oval. This finding suggests that both age groups use the same strategies for the task on the Plus, but different strategies on the Oval.

Analysis of the layout shift transfer helped to examine the source of the difference in layout and shape learning. In particular, the layout shift transfer was designed to assess three aspects of participant learning in the study: the degree of shape cue-letter mappings, the specificity of the shape transfer effect, and whether learning on the original shape reached optimal performance stage. Each aspect will be examined individually.

To determine whether participants learned the mappings of letters to shape cues, I calculated the layout shift transfer proportion scores. As presented in Table 14, all transfers were negative indicating that some degree of the learning was specific to where the individual letters were on the original shape.

Table 14
Proportion Scores for Layout Shift,((LS1-P16)/P16), by Shape, Age, and Layout

	Mean				Standard Deviation			
	Younger		Older		Younger		Older	
	Alphabetic	Standard	Alphabetic	Standard	Alphabetic	Standard	Alphabetic	Standard
Oval	0.35	0.33	0.15	0.24	0.18	0.20	0.10	0.10
Plus	0.40	0.23	0.31	0.23	0.21	0.14	0.11	0.17

This analysis does not, however, indicate whether the original learning was unique between an individual letter and a shape cue or between a subset of letters and the general area of the shape. I had expected that the Plus would facilitate unique learning but that the Oval would only facilitate general learning. Therefore, I conducted a univariate ANOVA to determine whether shape, age, or layout were significantly affected the layout shift proportion scores. Results showed a significant shape by layout effect ($F(1,56) = 4.17$, $p<.05$, $\eta^2=.07$). The Plus was significantly more affected in the Alphabetic layout, and the Oval was significantly more affected in the Standard layout as shown in Table 15. These results suggest that different strategies might have been used for different layouts, with unique letter-cue mappings learned for the Alphabetic layout but only general area mappings learned in the more difficult Standard layout. Hypothesis 9 was thus partially supported in predicting more transfer impact for Plus on Alphabetic but not in the higher transfer impact for Oval on Standard.

Table 15
Proportion Scores for Layout Shift, ((AS1-P16)/P16), by Shape and Layout

	Mean		Standard Deviation	
	Alphabetic	Standard	Alphabetic	Standard
Oval	0.25	0.28	0.18	0.16
Plus	0.36	0.23	0.17	0.15

The ANOVA also found a significant age effect whereby younger adults ($M = .33$, $SD = .19$) have significantly higher proportion scores than older adults ($M = .23$, $SD = .13$). As shown in Appendix F, the ANOVA of shape, layout, and age on difference scores did not reveal this age effect, probably because the higher overall level of older adult times compensated for the relatively higher impact of the shift for younger adults. These results suggest different strategies for younger adults that may have been more affected by the shift than for older adults such as a higher use of memory, as predicted in hypothesis 8 for shape transfer analysis. If this was the case, participants would be more affected by a new layout varied by shifting the letters than by transfer to a shape on which participants had already received some practice. This possibility was tested by analyzing the specificity of the cue/letter mapping used by participants for faster visual search.

To assess the specificity of the cue/letter mapping, a Repeated Measures ANOVA was used to analyze the effect of shape, age, and layout on the late shape and layout shift proportion scores. A significant main effect was found for transfer type ($F(1,56)=110.70$, $p<.001$, $\eta^2=.66$), supporting the Figure 11 demonstration that the layout shift transfer were significantly more negative than the late shape transfer. Significant interactions were found for age by transfer type ($F(1,56)=9.69$, $p<.01$, $\eta^2=.15$) and shape by transfer type ($F(1,56)=6.46$, $p<.05$, $\eta^2=.10$). A significant main effect was also found for layout ($F(1,56)=6.52$, $p<.05$, $\eta^2=.10$). The significant interactions and layout main effects provide a basis for analyzing the type of strategies used by different user groups and conditions for the task.

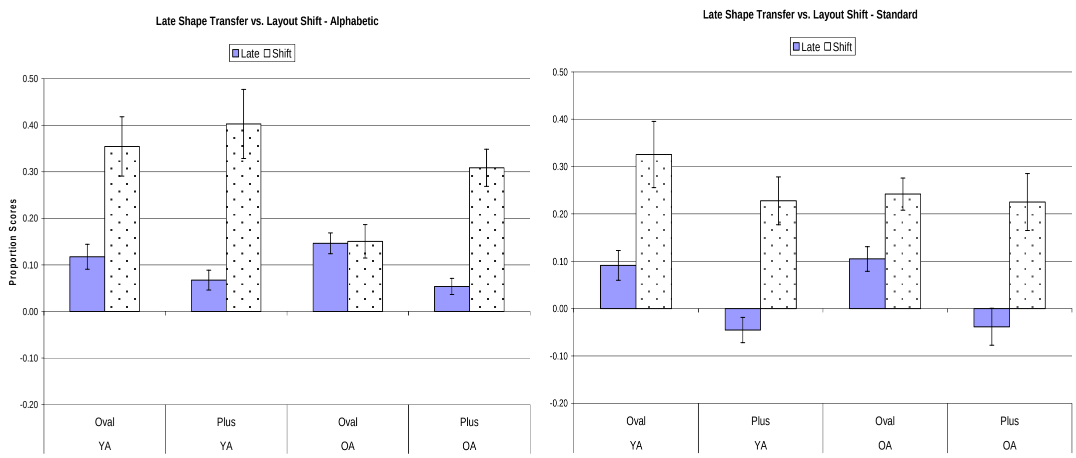

Figure 11. Proportion scores for late shape and layout shift transfers across age (YA = younger adult, OA = older adult) and layout, with the Alphabetic layout on the left and Standard layout on the right. Y-axis represents proportion scores, with the difference between block means (transfer – practice) divided by the practice block mean. Scores for the Oval shape are shown in solid shading, and scores for the Plus shape are shown with dotted shading. Negative values indicate positive transfer (faster entry time after transfer). Bars represent standard error.

In the Alphabetic layout, the younger adults on both shapes show similar patterns and levels of effect. This suggests that the same strategies were employed for both shapes. Given that shape-specific affordances were learned for both shapes in the Alphabetic layout by the late transfer, as well as the significantly different and higher negative transfer for the layout shift, it is likely that younger adults memorized unique letter/shape cue mappings. Older adults, however, appeared to use different search strategies by shape on the Alphabetic layout. In the Plus condition, older adults have the same pattern and transfer levels as the younger adults, suggesting that they use the same strategy with memorization of letter/cue mappings. In the Oval condition, however, older adults show a unique result in that the transfer types are not significantly different than each other (paired sample T-test $t(7)$ =-.084 , p = .935). This common transfer result suggests that the strategy participants used for each of these transfers was similar and it was the instance of a change rather than the specifics of the change causing the disruption in both cases. This result would be consistent with participants using the familiarity of the Oval shape and

Alphabetic layout to learn subsets of letters in general areas. To find a specific letter, they would still have to search within an area which would be harder with any change once the most common shape/layout combination was well-learned. Thus, the predictions for Alphabetic Plus and Standard (both shapes) in hypothesis 10 were supported, but the predictions for Alphabetic Oval were only supported in older adults.

Shape patterns and transfer levels were more consistent for the Standard layout. As noted earlier, Plus participants had not learned shape-specific affordances. They may have learned the general location of certain letters, which would have transferred well to the Oval in the shape transfer. Oval participants, however, had learned shape-specific affordances. Therefore, the finding that Oval participants were more affected by the layout shift, as shown in Table 15, was not surprising. In particular, if the shape-specific learning was based on movement compatibility and better movement planning, the layout shift would have interfered more by suggesting use of similar planning to the original layout but frustrating the plan as letters were in different locations on the keyboard or in opposite directions from previously. This result was interesting in its emphasis on optimal movements versus optimizing use of visual search as suggested in the other conditions. Hypothesis 10 was supported in the predictions for the Standard layout.

Consistent mapping and automaticity research suggests that participants have achieved optimal performance when practice has enabled them to reach performance levels at which a varied mapping change brings performance back to their original performance level. In this study, the layout shift transfer is similar to a varied mapping change. To analyze whether participants learned the task well in any condition, I calculated the overall performance difference between the mean of block P1 and the mean of block LS1. The difference value was used rather than the proportion score to emphasize levels of performance for each group. These differences are shown in Figure 12, with positive values indicating improved performance.

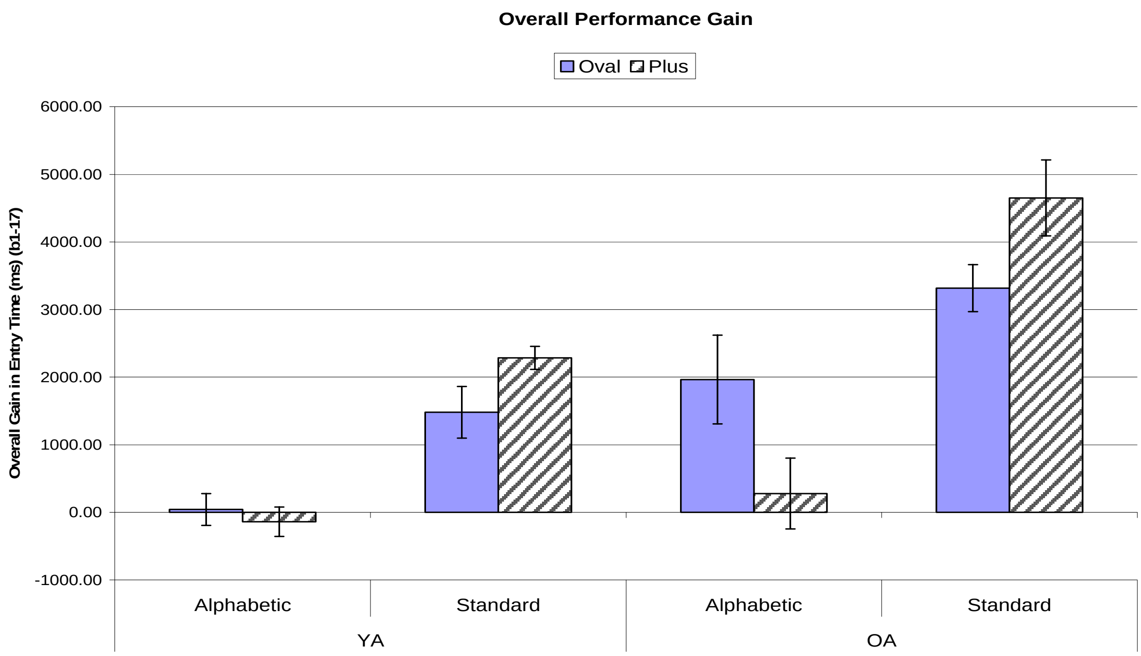

Figure 12. Overall performance gain during study. Performance is shown across layout and age (YA = younger adult, OA = older adult) and layout, with the Alphabetic layout on the left and Standard layout on the right. Y-axis represents the performance difference between the word entry mean in block P1 and the word entry mean in block LS1. Gains for the Oval shape are shown in solid shading, and scores for the Plus shape are shown with lined shading. Negative values indicate positive transfer (faster entry time after transfer). Bars represent standard error.

A univariate ANOVA on the effects of shape, age, and layout on overall gain found a significant interaction for shape by age ($F(1,56) = 11.29$, $p < .01$, $\eta^2 = .17$), along with main effects for age ($F(1,56) = 30.08$, $p < .001$, $\eta^2 = .35$) and layout ($F(1,56) = 64.66$, $p < .001$, $\eta^2 = .54$). The main effects are consistent with the practice results, whereby older adults improve more than younger adults and the Standard layout improves more than the Alphabetic layout.

To determine if overall gains were significantly different than 0, one-sample t-tests were run for each gain by shape, age, and layout condition. Results are shown in Table 16, whereby the gain was not significant for both shapes in the Alphabetic layout among younger adults and was not significant for Alphabetic Plus for older adults. All other gains were significant and positive. Earlier analysis suggests that younger adults on the Alphabetic layout facilitated the word entry task by memorizing letter/shape cue mappings for either shape, but older adults only memorized letter/shape cue mappings on the Plus shape. Thus, optimal performance for the given level of practice seems to be achieved through affordances that facilitate visual search as opposed to improved movement planning.

Table 16
T-Test results for overall gain, by age, layout, and shape.

		t		df		Sig. (2-tailed)	
		Oval	Plus	Oval	Plus	Oval	Plus
Younger	Alphabetic	0.18	-0.63	7	7	0.86	0.55
	Standard	3.88	13.42	7	7	*0.01*	*0.001*
Older	Alphabetic	2.99	0.53	7	7	*0.02*	0.61
	Standard	9.52	8.27	7	7	*0.001*	*0.001*

Note: Italics indicate significant *p* values (p<.05)

Older Adults on the Alphabetic Oval may have kept the task simpler by not developing any strategy as suggested by the comparison of transfer types, but this lack of strategy may have kept them from achieving their optimal performance level. The Standard layout was harder, so it is not surprising that no participants in any of the Standard conditions had sufficient practice to reach optimal performance on this harder layout. Hypothesis 11 was supported for younger adults, but older adults on the Alphabetic Plus condition also reached an optimal level of performance.

Learning Summary. Overall, the shape transfers suggest that the Plus promoted generalizable learning but the Oval promoted shape-specific learning. Shape transfer results combined with the layout shift results suggest that the easier Alphabetic layout facilitated memorization better than the Standard, particularly for younger adults. Comparison of the late transfer and the layout shift also imply that younger adults used specific letter/shape-cue mappings for both shapes on the Alphabetic layout, but older adults only memorized these mappings for the Plus. Evaluation of performance differences between the first block and the layout shift indicates that younger adults could use these memorized cues to achieve optimal performance on either shape for the Alphabetic layout, but older adults could only do so for the Plus shape on the Alphabetic layout. Optimal performance levels were not achieved for the Standard layout.

Overall Summary

Table 17 presents results from the practice and learning analysis, compared against the original hypotheses.

Table 17

Summary of Practice and Learning Results against Predictions.

Hypothesis	Prediction	Results
1	Plus faster than Oval	Not supported Younger, Period 4: Plus faster for Alphabetic; Oval faster for Standard
2	Less variability in entry times on Plus than Oval	Partially supported Less variability for Plus only on the Alphabetic layout in period 4
3	Alphabetic faster than Standard	Supported
4	Younger faster than Older	Supported
5	Alphabetic: positive transfers Standard: no transfer on Oval positive transfer on Plus	Partially supported Alphabetic: positive transfers Standard: positive transfers
6	Alphabetic: negative transfers; more transfer for Plus Standard: no transfer	Not supported Alphabetic: no transfer for Oval positive transfer for Plus; Standard: no transfer for Oval positive transfer for Plus
7	Alphabetic: negative transfers; more transfer for Plus Standard: negative transfers	Partially supported Alphabetic: negative transfers more impact for Oval Standard: negative transfer for Oval no transfer for Plus
8	Older: larger transfers in early shape transfer; smaller transfers in other transfers than younger	Not supported No age differences
9	Younger: negative transfers more transfer for Plus Older: negative transfer; more transfer for Alphabetic	Partially supported Alphabetic: negative transfers more impact for Plus Standard: negative transfers More transfer for Alphabetic
10	Alphabetic: Oval: layout shift = shape transfer Plus: layout shift > shape transfer; Standard: layout shift > shape transfer	Partially supported Alphabetic: Younger: layout shift > shape transfer; Older: Oval: layout shift = shape transfer Older: Plus : layout shift > shape transfer; Standard: layout shift > shape transfer
11	Younger on Alphabetic achieve optimal performance	Partially supported Younger: Alphabetic achieve optimal Older: Alphabetic Plus achieve optimal

DISCUSSION

In this study, text entry performance was examined in two ways: through practice on the same shape and layout over two days and through learning by assessing effects of shape transfers and layout shifts. The goals of the analysis were to identify which specific factors of the keyboard are important for effective text entry, to determine if there are age differences in how the keyboard was used, and to recommend design criteria for different levels of user experience.

Overall, keyboard shape did not significantly affect text entry performance at different levels of practice on the original shape. The Alphabetic layout was faster, though, and younger adults were faster than older adults. Keyboard shape does seem to have affected how participants completed the task, however. The Plus shape seems have promoted more generalizable learning, and the Oval shape seems to have promoted only shape-specific learning. The Standard layout made learning the general components of the task more difficult. The Alphabetic layout on the Plus shape promoted development of optimal performance levels for younger and older adults, but the Alphabetic layout on the Oval shape only allowed development of optimal performance levels for younger adults.

Performance on both shapes improved as a function of practice. Although there were no overall shape effects for the practice itself, shape effects did surface in transfers and in interactions with age and layout. Younger adults, for instance, reached optimal performance levels for both shapes on the Alphabetic layout, presumably by developing an effective schema to aid use of memorized letter/shape cue mappings. Presumably the schema matched the original practice shape for participants, but neither schema was better. The constraint for schema development, though, may have been the familiarity of the letter arrangement in the keyboard layout. If the layout is familiar, participants can use free resources to create a schema that can transfer and survive interference. If the layout is harder, participants may not be able to create a general schema, so the selection of the shape to suggest a memory schema is more critical. If participants will not be using a keyboard frequently enough to learn well the letter/shape cue mappings, use of shapes that help maintain or cue memory may have a protective effect against periods of inactivity or interfering tasks.

Older adults in this study, however, benefited specifically from the Plus shape. On the Alphabetic layout, they appear to have even used memorization to improve their performance, though previous research (e.g., Touron & Hertzog, 2004) suggests that they prefer not to use memory for visual search tasks. The unfamiliarity of the Plus shape, however, may have challenged older adults to make the task easier for themselves. After several trials, they may have realized that the corners provided some valuable search cues to an otherwise well-known Alphabetic layout. At that point, incidental learning through continued word entry facilitated memorization that proved to help the task, even after an overnight rest as shown with the lower variability at period 4 in the current experiment. For the harder Standard layout, however, the corners may have made some letters easier to find, memorization of specific locations or even the letters next to them would have been more difficult given the unfamiliar order.

Nonetheless, this experiment provides evidence that participants can learn and use even unfamiliar devices and keyboards for a familiar word entry task. Participants on the Standard layout continued to improve throughout the study, and improved at higher rates than the Alphabetic layout. Part of the difference could be attributable to the higher starting point for the unfamiliar layout, but the continued gains may also be due to the general effect Norman and Fisher (1982) found whereby participants can learn any arrangement with sufficient practice. A follow-up experiment could be run using the same shape, age, and layout conditions but additional daily practice to determine if in fact the Standard condition could be learned to the same performance level as the Alphabetic layout.

Other findings from this study suggest other important factors for training in environments where participants will need to learn more difficult shapes, movement options, or letter arrangements. As demonstrated by the lower variability and faster entry times at period 4, participants on the Alphabetic layout and Plus shape learned something that made their performance better. The improvement may have been due to more salient visual search cues that facilitated CM learning and performance (Fisk & Rogers, 1991). The improvement may also have been generally due to more varied performance on a less common shape that facilitated acquisition of a better mental schema or better motor skills with the device (Besnard & Cacitti, 2005, Magill & Hall 1990; Shea & Wulf, 2005). Alternatively, the Alphabetic layout may have only improved movement planning because participants could anticipate how far apart specific letters are or the forward/backward direction for the next letter in the word. Participants in both the Oval and Plus shapes, though, would have had equal amounts of practice using the alphabet in forward and backward order and varied distances to improve movement planning. Yet, only the Plus shape showed the lower variability, faster entry times, and optimal performance for older participants indicative of more effective learning. Overall, varied factors may help learning retention in environments where participants are using the system sporadically.

The current study partially contradicts previous research (Kurnaiwan, 2001) suggesting that older adults are more likely to use serial processing for this text entry task throughout the study although younger adults will adapt to a parallel processing mode if they can. In the Alphabetic Plus condition, both younger and older adults achieved optimal performance levels.

Additionally, there were no age differences in the patterns of disruption caused by shape transfers. These results suggest that both age groups were using the same strategy for the text entry. Given that younger adults are unlikely to work in a serial mode, particularly for this simple task, older adults must have adopted the parallel processing strategy as well. Thus, the Kurnaiwan results for older adults may be restricted to complex tasks or environments.

Another factor evaluated in this study was the relative contributions of movement and visual search to effectiveness in the combined word entry task. There was little evidence of movement optimization per se, though the varied movements through the corners and segments of the Plus versus the Oval may have triggered better motor skill development because of the contextual interference this variation introduced in practice. The trend toward better performance for Standard on the Oval shape also suggests that movement planning may have helped overall performance when the visual search portion of the task was difficult with a more unfamiliar layout. On the other hand, there was significant evidence of performance improvement that seemed to be due to better visual search or letter identification (which would be due to visual rather than movement learning). In particular, significant negative transfers from the Alphabetic Plus to a shifted layout indicate that participants had optimized performance based on visual search strategies, particularly memorization. When the layout was shifted, performance was significantly and substantially slower suggesting that participants were relying on well-learned letter/shape cue mappings to find letters and to plan movements. The visual search component of text entry may be particularly important for effective performance in systems that are used sporadically, whereby users are more likely to forget interface and movement specifics. Thus, design strategies that focus on improving visual search versus optimizing movements seem to be more important for novice and intermediate user environments, extending the findings of earlier studies that focused on novices (e.g., Zhai, Hunter, & Smith, 2002).

Visual search may also be fundamentally important when device movement allows little room for optimization such as the rotary controller. As shown in previous studies with this rotary controller (O'Brien et al., 2005), younger adults could very quickly use the rotary knob to reach optimal levels of performance on both the Oval and Plus shapes. Variations on the Plus shape itself, combined with shape transfers, may have provided interference that induced better motor skill acquisition, but the limits of that improvement may have been reached as indicated by the positive transfers for the Plus only through the middle transfer point. After that practice level, participants seemed to have learned shape-specific cues to improve visual search on the easier Alphabetic layout. On the harder Standard layout, they may have settled on shape-agnostic strategies as the older adults using the Alphabetic Oval did. Alternatively, they may started to memorize letter/shape cue mappings, but not been able to practice this enough to really develop a mental keyboard image. All of these alternatives still suggest that optimal visual search/memorization was the route to optimal performance. This factor would be particularly important with the selection method whereby visual attention was required to confirm that the cursor was on the correct letter. Thus, visual search appears to be the dominating design factor for this environment.

Eye tracking studies would help confirm whether the visual search strategies suggested by performance data are in fact used by participants on the different shapes and layouts. For instance, the Plus shape seems to afford fixations at the corners for improved search, though participants may in fact be looking in the center of each Plus segment. The strategies may differ by layout, for instance if the familiar Alphabetic layout allowed individuals to scan corners for a target letter but the unfamiliar Standard layout required individuals to look more carefully at each segment of the keyboard. Analysis of eye movement may also illustrate age differences in visual search strategies. Given the Touron and Hertzog (2004) research suggesting low use of memory strategies for visual search tasks by older adults, analysis may indicate the conditions in which they do use memorization. For instance, is there a period of time in which they are visually searching the keyboard with eye movements suggesting incidental learning before the memorization behavior seems to be adopted? Or, does different behavior surface after breaks that are reinforced by lower response times before adoption? What specifically is different about the other conditions in which memorization is not used for the same task? Thus, eye tracking data may suggest the specific effects that shape designs should target for improved performances in different user populations.

One practical application of this study can be found in the complementary practice and learning evaluation methods. In any environment in which user performance levels are considered, designers should consider the importance of using transfer to evaluate proposed factors in addition to basic performance tasks. The shape effects in this study were non-significant in the standard practice conditions, but the differences found in the transfers highlighted important considerations for design. When user performance levels are considered, designers should particularly evaluate whether they have any assumptions about what users know or will learn with practice on a particular system. By creating several types of transfers, researchers can measure whether the assumptions have been translated into the expected performance patterns.

This study has increased the research base about text entry with a rotary device on a virtual keyboard in several ways. First, the experiment demonstrated that participants can learn and use even unfamiliar devices and keyboards for a familiar word entry task. Second, selecting an effective shape for the virtual keyboard can help users learn to use the interface better for text entry, even when they will not be using the device frequently. Shapes with unique visual features facilitate effective learning. Third, selecting a well-known letter arrangement can not only help visual search, but it can also facilitate improved movement planning. Fourth, older adults may continue to be slower in this task than younger adults, but they can still reach an optimal performance level with selection of shapes and layouts that facilitate visual search. Finally, in this optimal environment, they can also execute the individual task components of visual search and movement in parallel mode.

Several guidelines for keyboard designers have also surfaced from this study, particularly with respect to system or task environments for occasional use. For this situation, designers should focus on optimizing elements that improve visual search. In the current study, the Plus provided shape cues that facilitated incidental learning of letter/shape cues, even for older adults. The Plus shape cues also served as unique visual elements that helped participants maintain or cue their memory for improved task execution. At least in the practice stage when users may be interacting with the device more frequently than usual to learn it, the unique Plus cues may have also provided variety to the basic cursor movement elements of the task, allowing better learning of motor control and movement planning. These guidelines can be generalized for other indirect devices used in a text entry system. Designers should consider creating visual search and uniqueness factors on a virtual keyboard that will blend with the compatibility and allowed movements for the selected device to create an effective virtual keyboard.

APPENDICES

Appendix A: Word List with Four Orders

Note: LN = word length; Freq. = word frequency according to Balota et al. 2002.

Order 1			Order 2			Order 3			Order 4		
LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.
5	ABOUT	1307019	6	RETURN	83751	5	OFTEN	117801	6	REASON	133687
6	RETURN	83751	5	ABOUT	1307019	5	ABOUT	1307019	5	OFTEN	117801
5	OFTEN	117801	5	OFTEN	117801	6	REASON	133687	5	ABOUT	1307019
6	REASON	133687	5	LIGHT	96805	5	ALONG	92602	6	CHANCE	58965
5	MAYBE	166009	6	REASON	133687	5	MAYBE	166009	5	ALONG	92602
5	LIGHT	96805	6	FAMILY	88710	6	RETURN	83751	5	LIGHT	96805
5	ALONG	92602	5	MAYBE	166009	6	FAMILY	88710	5	MAYBE	166009
6	FAMILY	88710	5	ALONG	92602	5	LIGHT	96805	4	COPY	126341
6	EASILY	52243	5	AFTER	414103	6	RESUME	80442	6	RESUME	80442
5	AFTER	414103	4	COPY	126341	6	EASILY	52243	5	AFTER	414103
6	RESUME	80442	6	EASILY	52243	4	COPY	126341	6	EASILY	52243
4	COPY	126341	6	RESUME	80442	5	AFTER	414103	4	BACK	393090
6	CHANCE	58965	6	CHANCE	58965	5	CHECK	170581	6	FAMILY	88710
6	PEOPLE	768168	4	BACK	393090	6	PEOPLE	768168	5	CHECK	170581
5	CHECK	170581	6	PEOPLE	768168	4	BACK	393090	6	RETURN	83751
4	BACK	393090	5	CHECK	170581	6	CHANCE	58965	6	PEOPLE	768168
5	TITLE	79977	4	THEY	1617818	4	HELP	335483	5	RIGHT	388384
4	THEY	1617818	5	RIGHT	388384	5	RIGHT	388384	4	HELP	335483
4	HELP	335483	5	TITLE	79977	4	THEY	1617818	4	THEY	1617818
5	RIGHT	388384	4	HELP	335483	5	FIELD	79920	5	TITLE	79977
5	VOICE	81827	4	EVEN	490549	5	VOICE	81827	6	NUMBER	283001
4	EVEN	490549	6	NUMBER	283001	6	NUMBER	283001	5	FIELD	79920
5	FIELD	79920	5	VOICE	81827	4	EVEN	490549	4	EVEN	490549
6	NUMBER	283001	5	FIELD	79920	6	HIGHER	61080	5	VOICE	81827
6	FUTURE	90741	4	PAGE	157108	5	TITLE	79977	4	SAID	352357
4	PAGE	157108	4	SAID	352357	6	FUTURE	90741	6	HIGHER	61080
6	HIGHER	61080	6	FUTURE	90741	4	SAID	352357	4	PAGE	157108
4	SAID	352357	6	HIGHER	61080	4	PAGE	157108	6	FUTURE	90741
6	MONTHS	100610	5	THANK	95706	4	NEXT	188009	6	ENOUGH	191008
5	THANK	95706	6	ENOUGH	191008	6	MONTHS	100610	4	NEXT	188009
4	NEXT	188009	6	MONTHS	100610	6	ENOUGH	191008	5	THANK	95706
6	ENOUGH	191008	4	NEXT	188009	5	THANK	95706	6	MONTHS	100610
5	MAJOR	100373	4	ABLE	176528	4	TIME	788823	4	SAME	401465
4	ABLE	176528	4	SAME	401465	5	MAJOR	100373	4	TIME	788823
4	TIME	788823	5	MAJOR	100373	4	SAME	401465	4	ABLE	176528
4	SAME	401465	4	TIME	788823	4	ABLE	176528	5	MAJOR	100373
5	WHILE	284228	6	PUBLIC	153537	5	EVERY	230149	5	UNTIL	170311
6	PUBLIC	153537	5	UNTIL	170311	5	WHILE	284228	5	EVERY	230149
5	EVERY	230149	5	WHILE	284228	5	UNTIL	170311	6	PUBLIC	153537

Order 1			Order 2			Order 3			Order 4		
LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.
5	UNTIL	170311	5	EVERY	230149	6	PUBLIC	153537	5	WHILE	284228
4	OVER	452595	4	OVER	452595	4	DONE	173968	5	NORTH	77220
5	WATER	105961	4	DONE	173968	4	OVER	452595	4	DONE	173968
4	DONE	173968	6	SHOULD	594293	5	NORTH	77220	5	WATER	105961
5	NORTH	77220	4	KIND	131849	5	WATER	105961	4	OVER	452595
5	SINCE	320454	5	SINCE	320454	5	FIRST	518924	4	KIND	131849
6	SHOULD	594293	5	FIRST	518924	4	KIND	131849	5	FIRST	518924
5	FIRST	518924	4	WHAT	1325779	6	SHOULD	594293	6	SHOULD	594293
4	KIND	131849	4	DATA	203945	6	INSIDE	63772	5	SINCE	320454
4	AREA	160430	4	AREA	160430	4	AREA	160430	4	DATA	203945
4	WHAT	1325779	6	INSIDE	63772	4	DATA	203945	6	INSIDE	63772
6	INSIDE	63772	6	STRONG	69234	4	WHAT	1325779	4	WHAT	1325779
4	DATA	203945	5	VIDEO	110183	6	ALWAYS	200870	4	AREA	160430
5	MUSIC	134404	5	MUSIC	134404	5	MUSIC	134404	5	VIDEO	110183
6	STRONG	69234	6	ALWAYS	200870	5	VIDEO	110183	6	ALWAYS	200870
6	ALWAYS	200870	4	SHOW	178842	6	STRONG	69234	6	STRONG	69234
5	VIDEO	110183	6	SAYING	95390	5	CLOSE	84927	5	MUSIC	134404
5	UNDER	250435	5	UNDER	250435	5	UNDER	250435	6	SAYING	95390
4	SHOW	178842	5	CLOSE	84927	6	SAYING	95390	5	CLOSE	84927
5	CLOSE	84927	4	WORK	451298	4	SHOW	178842	4	SHOW	178842
6	SAYING	95390	5	GROUP	284243	4	GIVE	230878	5	UNDER	250435
6	CLIENT	68130	6	CLIENT	68130	6	CLIENT	68130	5	GROUP	284243
4	WORK	451298	4	GIVE	230878	5	GROUP	284243	4	GIVE	230878
4	GIVE	230878	6	ANYONE	398422	4	WORK	451298	4	WORK	451298
5	GROUP	284243	4	THEM	801560	5	BEING	362268	6	CLIENT	68130
5	FORCE	75365	5	FORCE	75365	5	FORCE	75365	4	THEM	801560
6	ANYONE	398422	5	BEING	362268	4	THEM	801560	5	BEING	362268
5	BEING	362268	6	MEMBER	63948	6	ANYONE	398422	6	ANYONE	398422
4	THEM	801560	5	WROTE	1028146	4	MIND	131156	5	FORCE	75365
4	SOLD	189940	4	SOLD	189940	4	SOLD	189940	5	WROTE	1028146
6	MEMBER	63948	4	MIND	131156	5	WROTE	1028146	4	MIND	131156
4	MIND	131156	6	LIVING	75436	6	MEMBER	63948	6	MEMBER	63948
5	WROTE	1028146	6	ASKING	55492	6	SYSTEM	439448	4	SOLD	189940
4	FILE	311710	4	FILE	311710	4	FILE	311710	6	ASKING	55492
6	LIVING	75436	6	SYSTEM	439448	6	ASKING	55492	6	SYSTEM	439448
6	SYSTEM	439448	4	MOST	495365	6	LIVING	75436	6	LIVING	75436
6	ASKING	55492	5	BASED	131502	6	ENERGY	58596	4	FILE	311710
5	LATER	108034	5	LATER	108034	5	LATER	108034	5	BASED	131502
4	MOST	495365	6	ENERGY	58596	5	BASED	131502	6	ENERGY	58596
6	ENERGY	58596	4	WORD	138155	4	MOST	495365	4	MOST	495365
5	BASED	131502	6	SOCIAL	58169	6	CHANGE	157119	5	LATER	108034
5	REPLY	80908	5	REPLY	80908	5	REPLY	80908	6	SOCIAL	58169
4	WORD	138155	6	CHANGE	157119	6	SOCIAL	58169	6	CHANGE	157119
6	CHANGE	157119	5	EARLY	75759	4	WORD	138155	4	WORD	138155
6	SOCIAL	58169	6	BEHIND	64875	5	HUMAN	180168	5	REPLY	80908
4	FROM	1894943	4	FROM	1894943	4	FROM	1894943	6	BEHIND	64875
5	EARLY	75759	5	HUMAN	180168	6	BEHIND	64875	5	HUMAN	180168

Order 1			Order 2			Order 3			Order 4		
LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.
5	HUMAN	180168	4	YOUR	1711893	5	EARLY	75759	5	EARLY	75759
6	BEHIND	64875	4	WHEN	944467	5	BLACK	160756	4	FROM	1894943
6	TRYING	159951	6	TRYING	159951	6	TRYING	159951	4	WHEN	944467
4	YOUR	1711893	5	BLACK	160756	4	WHEN	944467	5	BLACK	160756
5	BLACK	160756	6	NORMAL	70982	4	YOUR	1711893	4	YOUR	1711893
4	WHEN	944467	6	OBJECT	52354	5	POWER	187656	6	TRYING	159951
6	MARKET	98850	6	MARKET	98850	6	MARKET	98850	6	OBJECT	52354
6	NORMAL	70982	5	POWER	187656	6	OBJECT	52354	5	POWER	187656
5	POWER	187656	6	SINGLE	94811	6	NORMAL	70982	6	NORMAL	70982
6	OBJECT	52354	5	ABOVE	177919	5	START	172475	6	MARKET	98850
5	START	172475	5	START	172475	5	ABOVE	177919	5	ABOVE	177919
6	SINGLE	94811	6	RECENT	61027	6	SINGLE	94811	6	RECENT	61027
6	RECENT	61027	6	AUTHOR	53382	6	BOUGHT	57147	6	SINGLE	94811
5	ABOVE	177919	5	AGAIN	249680	6	REPORT	90838	5	START	172475
6	REPORT	90838	6	REPORT	90838	5	AGAIN	249680	5	AGAIN	249680
6	AUTHOR	53382	6	BOUGHT	57147	6	AUTHOR	53382	6	BOUGHT	57147
6	BOUGHT	57147	4	ALSO	782967	6	DRIVER	69007	6	AUTHOR	53382
5	AGAIN	249680	5	PLACE	195199	5	WHITE	149742	6	REPORT	90838
5	WHITE	149742	5	WHITE	149742	5	PLACE	195199	5	PLACE	195199
4	ALSO	782967	6	DRIVER	69007	4	ALSO	782967	6	DRIVER	69007
6	DRIVER	69007	4	INTO	563310	5	WORTH	81429	4	ALSO	782967
5	PLACE	195199	6	HEALTH	60950	4	DOWN	293731	5	WHITE	149742
4	DOWN	293731	4	DOWN	293731	6	HEALTH	60950	6	HEALTH	60950
4	INTO	563310	5	WORTH	81429	4	INTO	563310	5	WORTH	81429
5	WORTH	81429	4	IDEA	133710	6	MEMORY	114930	4	INTO	563310
6	HEALTH	60950	4	NAME	297695	6	COMING	72956	4	DOWN	293731
6	COMING	72956	6	COMING	72956	4	NAME	297695	4	NAME	297695
4	IDEA	133710	6	MEMORY	114930	4	IDEA	133710	6	MEMORY	114930
6	MEMORY	114930	4	PART	249067	6	ANSWER	109246	4	IDEA	133710
4	NAME	297695	5	THESE	591805	4	SOME	1042740	6	COMING	72956
4	SOME	1042740	4	SOME	1042740	5	THESE	591805	5	THESE	591805
4	PART	249067	6	ANSWER	109246	4	PART	249067	6	ANSWER	109246
6	ANSWER	109246	4	LINE	239804	4	GAME	197271	4	PART	249067
5	THESE	591805	4	REAL	197763	6	RATHER	146049	4	SOME	1042740
6	RATHER	146049	6	RATHER	146049	4	REAL	197763	4	REAL	197763
4	LINE	239804	4	GAME	197271	4	LINE	239804	6	RATHER	146049
4	GAME	197271	4	LAST	291284	4	BEST	269708	6	RESULT	66995
4	REAL	197763	6	EXPECT	60322	6	THOUGH	199366	4	BEST	269708
6	THOUGH	199366	6	THOUGH	199366	6	RESULT	66995	4	LAST	291284
4	LAST	291284	4	BEST	269708	4	LAST	291284	6	THOUGH	199366
4	BEST	269708	4	NOTE	131657	4	ONCE	188862	5	LEVEL	130029
6	RESULT	66995	5	LEVEL	130029	5	USING	339069	4	ONCE	188862
5	USING	339069	5	USING	339069	5	LEVEL	130029	4	NOTE	131657
4	NOTE	131657	4	ONCE	188862	4	NOTE	131657	5	USING	339069
4	ONCE	188862	6	PERSON	167439	4	LIFE	219561	4	MUCH	483898
5	LEVEL	130029	4	MUCH	483898	6	PLEASE	580704	4	LIFE	219561
6	PLEASE	580704	6	PLEASE	580704	4	MUCH	483898	6	PERSON	167439

Order 1			Order 2			Order 3			Order 4		
LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.	LN	Word	Freq.
6	PERSON	167439	4	LIFE	219561	6	PERSON	167439	6	PLEASE	580704
4	LIFE	219561	6	AMOUNT	61858	5	COULD	544756	4	TAKE	330816
4	MUCH	483898	4	TAKE	330816	6	BECOME	93420	5	COULD	544756
6	BECOME	93420	6	BECOME	93420	4	TAKE	330816	6	AMOUNT	61858
6	AMOUNT	61858	5	COULD	544756	6	AMOUNT	61858	6	BECOME	93420
5	COULD	544756	5	TRIED	119845	6	EXPECT	60322	4	OPEN	145040
4	TAKE	330816	4	OPEN	145040	4	CARD	222822	6	EXPECT	60322
4	CARD	222822	4	CARD	222822	4	OPEN	145040	5	TRIED	119845
5	TRIED	119845	6	RESULT	66995	5	TRIED	119845	4	CARD	222822
6	EXPECT	60322	5	VALUE	82888	6	MYSELF	92699	4	POST	275951
4	OPEN	145040	4	POST	275951	6	SEARCH	78523	6	MYSELF	92699
6	SEARCH	78523	6	SEARCH	78523	4	POST	275951	5	VALUE	82888
5	VALUE	82888	6	MYSELF	92699	5	VALUE	82888	6	SEARCH	78523
6	MYSELF	92699	6	EXCEPT	83885	5	SENSE	77530	4	HOME	190434
4	POST	275951	4	HOME	190434	6	SECOND	150377	5	SENSE	77530
6	SECOND	150377	6	SECOND	150377	4	HOME	190434	6	EXCEPT	83885
6	EXCEPT	83885	5	SENSE	77530	6	EXCEPT	83885	6	SECOND	150377
5	SENSE	77530	5	WORLD	295523	5	KNOWN	84923	6	MAKING	119373
4	HOME	190434	6	MAKING	119373	6	ENTIRE	62545	5	KNOWN	84923
6	ENTIRE	62545	6	ENTIRE	62545	6	MAKING	119373	5	WORLD	295523
5	WHOLE	120697	5	KNOWN	84923	5	WORLD	295523	6	ENTIRE	62545
5	KNOWN	84923	6	ALMOST	111601	5	QUITE	155011	5	LOCAL	139852
6	MAKING	119373	5	LOCAL	139852	5	GOING	305772	5	WHOLE	120697
5	GOING	305772	5	GOING	305772	6	ALMOST	111601	6	ALMOST	111601
6	ALMOST	111601	5	WHOLE	120697	4	HOPE	150675	5	GOING	305772
5	WORLD	295523	4	SUCH	371015	5	WHOLE	120697	4	BOTH	296623
5	LOCAL	139852	4	BOTH	296623	4	BOTH	296623	4	HOPE	150675
5	QUITE	155011	5	QUITE	155011	4	SUCH	371015	4	SUCH	371015
4	SUCH	371015	4	HOPE	150675	6	ANYWAY	96987	5	QUITE	155011
4	HOPE	150675	5	WRONG	138848	6	CENTER	87347	4	HARD	176370
4	BOTH	296623	4	HARD	176370	4	HARD	176370	6	ANYWAY	96987
6	CENTER	87347	6	CENTER	87347	5	WRONG	138848	5	WRONG	138848
5	WRONG	138848	6	ANYWAY	96987	5	BELOW	90658	6	CENTER	87347
6	ANYWAY	96987	4	DOES	525612	6	SIMPLY	102396	6	USEFUL	55233
4	HARD	176370	6	USEFUL	55233	6	USEFUL	55233	5	BELOW	90658
6	SIMPLY	102396	6	SIMPLY	102396	4	DOES	525612	4	DOES	525612
4	DOES	525612	5	BELOW	90658	6	FIGURE	56510	6	SIMPLY	102396
5	BELOW	90658	4	EACH	303525	5	FOUND	199981	6	LIKELY	71675
6	USEFUL	55233	6	LIKELY	71675	6	LIKELY	71675	6	FIGURE	56510
5	FOUND	199981	5	FOUND	199981	4	EACH	303525	4	EACH	303525
4	EACH	303525	6	FIGURE	56510	6	ACTION	77756	5	FOUND	199981
6	FIGURE	56510	5	ASKED	102158	4	WANT	508123	5	ORDER	193686
6	LIKELY	71675	5	ORDER	193686	5	ORDER	193686	6	ACTION	77756
4	WANT	508123	4	WANT	508123	5	ASKED	102158	5	ASKED	102158
5	ASKED	102158	6	ACTION	77756	5	SOUND	122381	4	WANT	508123
6	ACTION	77756	4	COME	232041	4	MEAN	151693	4	LOVE	165830
5	ORDER	193686	4	LOVE	165830	4	LOVE	165830	5	SOUND	122381

Order 1			Order 2			Order 3			Order 4		
LN	**Word**	**Freq.**	**LN**	**Word**	**Freq.**	**LN**	**Word**	**Freq.**	**LN**	**Word**	**Freq.**
4	MEAN	151693	4	MEAN	151693	4	COME	232041	4	COME	232041
4	COME	232041	5	SOUND	122381	5	LEAST	201524	4	MEAN	151693
5	SOUND	122381	4	AWAY	150815	4	SURE	260476	5	THINK	652944
4	LOVE	165830	5	THINK	652944	5	THINK	652944	5	LEAST	201524
4	SURE	260476	4	SURE	260476	4	AWAY	150815	4	AWAY	150815
4	AWAY	150815	5	LEAST	201524	5	SPACE	113076	4	SURE	260476
5	LEAST	201524	4	JUST	1020539	5	FRONT	77889	6	AROUND	268131
5	THINK	652944	6	AROUND	268131	6	AROUND	268131	5	SPACE	113076
5	FRONT	77889	5	FRONT	77889	4	JUST	1020539	4	JUST	1020539
4	JUST	1020539	5	SPACE	113076	4	TYPE	157464	5	FRONT	77889
5	SPACE	113076	6	CHOICE	65532	5	SHORT	95521	6	RECORD	61996
6	AROUND	268131	6	RECORD	61996	6	RECORD	61996	4	TYPE	157464
5	SHORT	95521	5	SHORT	95521	6	CHOICE	65532	6	CHOICE	65532
6	CHOICE	65532	4	TYPE	157464	4	NEWS	149044	5	SHORT	95521
4	TYPE	157464	4	CASE	199506	4	SEND	324164	4	WERE	663883
6	RECORD	61996	4	WERE	663883	4	WERE	663883	4	NEWS	149044
4	SEND	324164	5	PHONE	141619	5	PRICE	153716	4	CASE	199506
4	CASE	199506	4	MANY	474923	4	LONG	273917	5	PRICE	153716
4	NEWS	149044	4	LONG	273917	4	MANY	474923	5	PHONE	141619
5	PHONE	141619	5	PRICE	153716	5	PHONE	141619	4	LONG	273917
5	PRICE	153716	4	INFO	159678	5	HOURS	77067	5	THOSE	415648
4	MANY	474923	5	THOSE	415648	4	ONLY	828014	5	HOURS	77067
4	ONLY	828014	4	ONLY	828014	5	THOSE	415648	4	INFO	159678
4	AWAY	150815	5	HOURS	77067	4	INFO	159678	4	FIND	378725
5	HOURS	77067	5	STORY	96953	5	NEVER	303028	4	ONLY	828014
5	THOSE	415648	4	FIND	378725	5	HEARD	133757	5	NEVER	303028
5	HEARD	133757	5	HEARD	133757	4	FIND	378725	5	STORY	96953
4	FIND	378725	5	NEVER	303028	5	STORY	96953	5	HEARD	133757
6	FRIEND	81053	6	DESIGN	110689	6	CREATE	73169	4	YEAR	246566
6	DESIGN	110689	4	YEAR	246566	6	FRIEND	81053	6	CREATE	73169
6	CREATE	73169	6	FRIEND	81053	4	YEAR	246566	6	DESIGN	110689
4	YEAR	246566	6	CREATE	73169	6	DESIGN	110689	6	FRIEND	81053
5	OTHER	897942	4	MORE	1076711	6	SERIES	90751	4	MORE	1076711
4	MORE	1076711	6	BEFORE	344936	5	OTHER	897942	5	OTHER	897942
6	SERIES	90751	5	OTHER	897942	6	BEFORE	344936	5	CLEAR	77302
6	BEFORE	344936	6	SERIES	90751	4	MORE	1076711	4	LEFT	132017
4	CODE	148173	5	CAUSE	79705	4	LEFT	132017	5	CAUSE	79705
5	CAUSE	79705	5	CLEAR	77302	4	CODE	148173	4	CODE	148173
4	LEFT	132017	4	CODE	148173	5	CLEAR	77302	5	HOUSE	104153
5	CLEAR	77302	4	LEFT	132017	5	CAUSE	79705	6	PERIOD	53751
4	ELSE	176434	6	MASTER	54412	6	PERIOD	53751	6	MASTER	54412
6	MASTER	54412	5	HOUSE	104153	4	ELSE	176434	4	ELSE	176434
6	PERIOD	53751	4	ELSE	176434	5	HOUSE	104153	6	PLAYED	66128
5	HOUSE	104153	6	PERIOD	53751	6	MASTER	54412	4	MUST	306094
5	TODAY	103604	5	DOING	166241	4	MUST	306094	5	DOING	166241
5	DOING	166241	6	PLAYED	66128	5	TODAY	103604	5	TODAY	103604
4	MUST	306094	5	TODAY	103604	6	PLAYED	66128	5	POINT	256288

Order 1			Order 2			Order 3			Order 4		
LN	**Word**	**Freq.**	**LN**	**Word**	**Freq.**	**LN**	**Word**	**Freq.**	**LN**	**Word**	**Freq.**
6	PLAYED	66128	4	MUST	306094	5	DOING	166241	6	EITHER	192195
6	HAVING	166984	4	LIKE	1060831	6	EITHER	192195	4	LIKE	1060831
4	LIKE	1060831	5	POINT	256288	6	HAVING	166984	6	HAVING	166984
6	EITHER	192195	6	HAVING	166984	5	POINT	256288	5	MIGHT	277738
5	POINT	256288	6	EITHER	192195	4	LIKE	1060831	5	BOARD	79617
4	LIST	317096	6	ITSELF	76297	5	BOARD	79617	6	ITSELF	76297
6	ITSELF	76297	5	MIGHT	277738	4	LIST	317096	4	LIST	317096
5	BOARD	79617	4	LIST	317096	5	MIGHT	277738	4	USED	365662
5	MIGHT	277738	5	BOARD	79617	6	ITSELF	76297	6	WITHIN	120308
5	GREAT	260267	6	THREAD	57162	6	WITHIN	120308	6	THREAD	57162
6	THREAD	57162	4	USED	365662	5	GREAT	260267	5	GREAT	260267
6	WITHIN	120308	5	GREAT	260267	4	USED	365662	4	FACT	184510
4	USED	365662	6	WITHIN	120308	6	THREAD	57162	6	COUPLE	93448
5	NIGHT	97524	6	FORMAT	79019	6	COUPLE	93448	6	FORMAT	79019
6	FORMAT	79019	4	FACT	184510	5	NIGHT	97524	5	NIGHT	97524
6	COUPLE	93448	5	NIGHT	97524	4	FACT	184510	4	MAKE	520909
4	FACT	184510	6	COUPLE	93448	6	FORMAT	79019	6	COURSE	195947
5	MONEY	209588	6	UNITED	82140	6	COURSE	195947	6	UNITED	82140
6	UNITED	82140	4	MAKE	520909	5	MONEY	209588	5	MONEY	209588
6	COURSE	195947	5	MONEY	209588	4	MAKE	520909	5	LARGE	134354
4	MAKE	520909	6	COURSE	195947	6	UNITED	82140	4	VERY	587578
6	SERVER	163334	4	VERY	587578	5	LARGE	134354	6	SERVER	163334
4	VERY	587578	6	SERVER	163334	6	SERVER	163334	4	GAME	197271
5	LARGE	134354	5	LARGE	134354	4	VERY	587578	4	LINE	239804
4	WERE	663883	5	WATER	105961	5	SINCE	320454	6	BEFORE	344936
5	STORY	96953	5	NORTH	77220	6	RECENT	61027	6	SERIES	90751
5	NEVER	303028	4	SEND	324164	5	LOCAL	139852	4	SEND	324164
4	LONG	273917	4	NEWS	149044	4	CASE	199506	4	MANY	474923

Appendix B: Counterbalance order

Participant number	layout	Original shape	Transfer shape	word order	Age Group
201	alphabetic	plus	oval	1	Older
202	alphabetic	oval	plus	2	Older
203	alphabetic	plus	oval	3	Older
204	alphabetic	oval	plus	4	Older
205	alphabetic	plus	oval	1	Older
206	alphabetic	oval	plus	2	Older
207	alphabetic	plus	oval	3	Older
208	alphabetic	oval	plus	4	Older
209	alphabetic	plus	oval	1	Older
210	alphabetic	oval	plus	2	Older
211	alphabetic	plus	oval	3	Older
212	alphabetic	oval	plus	4	Older
213	alphabetic	plus	oval	1	Older
214	alphabetic	oval	plus	2	Older
215	alphabetic	plus	oval	3	Older
216	alphabetic	oval	plus	4	Older
217	standard	plus	oval	1	Older
218	standard	oval	plus	2	Older
219	standard	plus	oval	3	Older
220	standard	oval	plus	4	Older
221	standard	plus	oval	1	Older
222	standard	oval	plus	2	Older
223	standard	plus	oval	3	Older
224	standard	oval	plus	4	Older
225	standard	plus	oval	1	Older
226	standard	oval	plus	2	Older
227	standard	plus	oval	3	Older
228	standard	oval	plus	4	Older
229	standard	plus	oval	1	Older
230	standard	oval	plus	2	Older
231	standard	plus	oval	3	Older
232	standard	oval	plus	4	Older
101	alphabetic	plus	oval	1	Younger
102	alphabetic	oval	plus	2	Younger
103	alphabetic	plus	oval	3	Younger
104	alphabetic	oval	plus	4	Younger
105	alphabetic	plus	oval	1	Younger
106	alphabetic	oval	plus	2	Younger
107	alphabetic	plus	oval	3	Younger
108	alphabetic	oval	plus	4	Younger
109	alphabetic	plus	oval	1	Younger
110	alphabetic	oval	plus	2	Younger
111	alphabetic	plus	oval	3	Younger
112	alphabetic	oval	plus	4	Younger

113	alphabetic	plus	oval	1	Younger
114	alphabetic	oval	plus	2	Younger
115	alphabetic	plus	oval	3	Younger
116	alphabetic	oval	plus	4	Younger
117	standard	plus	oval	1	Younger
118	standard	oval	plus	2	Younger
119	standard	plus	oval	3	Younger
120	standard	oval	plus	4	Younger
121	standard	plus	oval	1	Younger
122	standard	oval	plus	2	Younger
123	standard	plus	oval	3	Younger
124	standard	oval	plus	4	Younger
125	standard	plus	oval	1	Younger
126	standard	oval	plus	2	Younger
127	standard	plus	oval	3	Younger
128	standard	oval	plus	4	Younger
129	standard	plus	oval	1	Younger
130	standard	oval	plus	2	Younger
131	standard	plus	oval	3	Younger
132	standard	oval	plus	4	Younger

Appendix C: Questionnaires

Demographics Questionnaire

Note: This was given to participants in 14 point font. Font was reduced in this report to save space.

Gender: $_1$ Male $_2$ Female **Age:** _________

1. Education <u>completed</u> (check <u>highest</u> level)

1 Less than high school graduate
(highest grade completed? ________)

2 High school graduate/G.E.D.

3 Some college, or trade, technical, or business school

(how many years? _________)

4 Bachelor's degree

5 Some graduate work (how many years? _____)

6 Master's degree

7 M.D., J.D., Ph.D., other advanced degree

2. Current marital status (check <u>one</u>)

1 Single

2 Married

3 Separated

4 Divorced

5 Widowed

6 Other (please specify _________________)

3. Race/ethnicity

1 Black/African American

2 Asian American/Pacific Islander

3 White/Caucasian

4 Hispanic/Latino

5 American Indian/Alaskan Native

6 Multiracial (please specify ____________)

7 Other (please specify ________________)

4. In which type of housing do you live?

1 Residence hall/College dormitory

2 House/Apartment/Condominium

3 Senior housing (independent)

4 Assisted living

5 Nursing home

6 Relative's home

7 Other (please specify ________________)

5. Do you live alone a majority of the year?

1 Yes 2 No

6. What is your primary language?

1 English

2 Spanish

3 French

4 Creole

5 Portuguese

6 Other _________

7. Occupational status (check <u>all</u> that apply)

1 Working full-time

2 Working part-time

3 Student

4 Homemaker

5 Retired

6 Volunteer worker

7 Seeking employment, laid off, etc.

8 Leave of absence

9 Other (please specify):

8. What is your current occupation? _____________________________

<u>If retired:</u>

9. What was your primary occupation? __________________________

10. What year did you retire? __________________

Health Information

1. In general would you say your health is:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

2. Compared to other people your own age, would you say your health is:

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent

3. How satisfied are you with your present health?

1	2	3	4	5
Not At All Satisfied	Not Very Satisfied	Neither Satisfied Nor Dissatisfied	Somewhat Satisfied	Extremely Satisfied

4. How often do health problems stand in the way of your doing the things you want to do?

1	2	3	4	5
Never	Seldom	Sometimes	Often	Always

5. Have you ever lost consciousness for more than 10 minutes because of a head injury?

1 Yes 2 No

6. The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much? Select one box for each type of activity.

	Yes$_1$, **Limited a Lot**	Yes$_2$, **Limited a Little**	No$_3$, **Not Limited at all**
a. Vigorous activities, such as running, lifting heavy objects, or participating in strenuous sports (like swimming laps)			
b. Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf			
c. Lifting or carrying groceries			
d. Climbing **several** flights of stairs			
e. Climbing **one** flight of stairs			
f. Bending, kneeling, or stooping			
g. Walking **more than a mile**			
h. Walking **several blocks**			
i. Walking **one block**			
j. Bathing or dressing yourself			

7. Are you on post-menopausal estrogen replacement therapy?

1 Yes 2 No 3 Not Applicable

8. Do you take any medications (prescription or nonprescription) on a regular basis (at least once a week)?

1 Yes 2 No

9. Please check which of following conditions you have now or have had in the past.

Condition	**In Your Lifetime$_1$**	**Now$_2$**
a. Asthma or Bronchitis		
b. Cancer (other than skin cancer)		
c. Chronic liver disease or hepatitis		
d. Chronic migraine headaches		
e. Diabetes		
f. Emphysema		
g. Encephalitis or meningitis		
h. Epilepsy		
i. Heart attack or bypass surgery		
j. Heart problems		
k. High blood pressure		
l. Kidney disease		
m. Leukemia		
n. Multiple sclerosis		
o. Parkinson's disease		
p. Pneumonia		
q. Rheumatoid arthritis or other autoimmune disorders		
r. Stomach ulcers		
s. Stroke		
t. Other significant illnesses (please list)		

10. How many BONE FRACTURES have you had in the LAST FIVE YEARS?

1 None
2 1
3 2
4 3-5
5 More than 5

11. How many SURGERIES have you had in the LAST FIVE YEARS?

1 None
2 1
3 2
4 3-5
5 More than 5

12. How many times have you been HOSPITALIZED in the LAST FIVE YEARS?

1 None
2 1
3 2
4 3-5
5 6-10
6 More than 10

Medication Usage Details

Please list all medical products that you are currently taking. Include medicinal herbs, vitamins, aspirin, antacid, nasal spray, laxatives, etc., as well as prescription medications (copy names from label if possible). This information will be completely confidential.

Example

Name of Medication: Zarontin

Reason for taking:____epilepsy___ Dosage (ea. time taken): 500 mg

How often do you take the medication? (circle one)

daily every other day weekly as needed

On days that you take the medication, how many times per day do you take it? 3

What time of day do you take the medication? morning, afternoon, evening

How long you have been taking the medication? 5 years Does this medication cause any problems? makes me sleepy

1. Name of Medication: ____
Reason for taking:______________________ Dosage (ea. time taken):________

How often do you take the medication? (circle one)
daily every other day weekly as needed

On days that you take the medication, how many times per day do you take it?
What time of day do you take the medication?

How long you have been taking medication? ____________________________

Does this medication cause any problems?

This box repeated 9 times to allow for 9 medications to be noted. Additional pages were also allowed.

Technology Questionnaire

Note: This was given to participants in 14 point font. Font was reduced in this report to save pace.

The purpose of this set of questions is to assess your familiarity and experience with technology. Please answer all questions by placing a check mark at the appropriate response.

1. How often do you communicate with other people (e.g., family members, friends, doctors, customer service representatives)?

   - ☐1 Daily
   - ☐2 Weekly
   - ☐3 Monthly
   - ☐4 Yearly
   - ☐5 Never

2. Within the last year, which of the following methods have you **used** for communication?

	Not sure what it is1	Never2	Once in a while3	Some of the time4	Most of the time5	Always6
1. Answering machine						
2. Cell phone						
3. Fax machine						
4. Internet (e.g., e-mail, chat room, videoconferencing)						
5. Telephone						
6. Videophone						

3. How often do you go shopping?

   - ☐1 Daily
   - ☐2 Weekly
   - ☐3 Monthly
   - ☐4 Yearly
   - ☐5 Never

4. Within the last year, which of the following have you **used** for shopping?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Credit card						
2. Debit card						
3. In-store automated kiosk (e.g., self-checkout, price scanner, item locator)						
4. Internet (e.g., on-line purchasing, on-line product evaluation)						
5. Telephone						
6. Television shopping						

5. How often do you use customer service functions (e.g., technical support, product assistance, reservations)?

- ☐$_1$ Daily
- ☐$_2$ Weekly
- ☐$_3$ Monthly
- ☐$_4$ Yearly
- ☐$_5$ Never

6. Within the last year, which of the following have you **used** for customer service (e.g., technical support, product assistance, reservations)?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Automated telephone menu system						
2. CD/DVD						
3. E-mail						
4. Fax machine						
5. Internet (e.g., on-line manuals, on-line interactive support, web site)						
6. Person on the telephone						

7. How often do you make financial transactions (e.g., bill paying, banking, investing/ financial planning, tax preparation)?

- ☐$_1$ Daily
- ☐$_2$ Weekly
- ☐$_3$ Monthly
- ☐$_4$ Yearly
- ☐$_5$ Never

8. Within the last year, which of the following have you **used** for financial transactions (e.g., bill paying, banking, investing/financial planning, tax preparation)?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Automated telephone menu system (e.g., banking, credit card information)						
2. Automatic teller machine (ATM)						
3. Drive-through banking						
4. Internet (e.g., on-line banking, on-line bill paying, on-line investing)						
5. Person on the telephone						
6. Software (e.g., Quicken, spreadsheet, MS Money, TurboTax)						

9. How often do you engage in healthcare related activities for yourself or others (e.g., going to see a doctor, checking blood pressure, finding information about a disease or medication)?

☐$_1$ Daily

☐$_2$ Weekly

☐$_3$ Monthly

☐$_4$ Yearly

☐$_5$ Never

10. Within the last year, which of the following have you **used** for healthcare related activities for yourself or others?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Automated telephone menu system						
2. Health information searching on the Internet						
3. Internet communication (e.g., e-mail, computer support groups)						
4. Medical-related Internet purchasing (e.g., medication or medical supplies)						
5. Person on the telephone						
6. Telemedicine (e.g., videoconferencing with doctors or nurses)						

11. How often do you use healthcare devices at home for yourself or others (e.g., glucose monitor, blood pressure monitor)?

☐$_1$ Daily
☐$_2$ Weekly
☐$_3$ Monthly
☐$_4$ Yearly
☐$_5$ Never

12. Within the last year, which of the following healthcare devices have you **used** in your home?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Blood pressure measurement device						
2. Digital thermometer						
3. Electronic dental hygiene system (e.g., electric toothbrush, Waterpik)						
4. Emergency call system (e.g., Lifeline)						
5. Heating pads						
6. Infusion pump						
7. Monitoring device (e.g., glucose, apnea, cardiac)						
8. Nebulizers						
9. Oxygen equipment						

13. How often do you use public transportation (e.g., train, bus, subway)?

☐$_1$ Daily

☐$_2$ Weekly

☐$_3$ Monthly

☐$_4$ Yearly

☐$_5$ Never

14. How often do you drive?

☐$_1$ Daily

☐$_2$ Weekly

☐$_3$ Monthly

☐$_4$ Yearly

☐$_5$ Never

15. How often do you travel by airplane?

☐$_1$ Weekly

☐$_2$ Monthly

☐$_3$ Quarterly

☐$_4$ Yearly

☐$_5$ Never

16. Within the last year, which of the following transportation-related systems have you **used**?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Automated telephone menu system						
2. Automatic check-in station						
3. Automatic parking payment station						
4. Automatic ticket purchase station						
4. Cruise control in your car						
5. In-car navigation system (e.g., GPS, OnStar, Neverlost)						
6. On-line travel schedule						
7. Personal digital assistant (PDA)						
8. Person on the phone						
9. Remote control to start the car						
10. Travel direction/ map software (e.g., MapQuest, Streets & Trips)						

17. How often do you engage in leisure/hobby/entertainment-related activities?

- ☐ 1 Daily
- ☐ 2 Weekly
- ☐ 3 Monthly
- ☐ 4 Yearly
- ☐ 5 Never

18. Within the last year, which of the following leisure/hobby/entertainment-related systems have you **used**?

	Not sure what it is 1	Never 2	Once in a while 3	Some of the time 4	Most of the time 5	Always 6
1. Books on tape (audio book)						
2. Computer/Video game (e.g., Gameboy, PlayStation, Nintendo, GameCube, X-Box)						
3. Digital photography (e.g., camera, camcorder)						
4. Fitness device (e.g., pedometer, pulse meter, golf swing enhancer, treadmill)						
5. Hobby-specific computer usage (e.g., Internet, Photoshop, genealogy software, patterns)						
6. MP3/IPOD						
7. Personal digital assistant (PDA)						
8. Recording and playback device (e.g., CD, DVD, VCR)						
9. TV set-top box (e.g., program TV, pay-per view movies, music stations, TiVo)						

19. How often do you engage in learning/educational/self-help activities?

- ☐$_1$ Daily
- ☐$_2$ Weekly
- ☐$_3$ Monthly
- ☐$_4$ Yearly
- ☐$_5$ Never

20. Within the last year, which of the following learning/educational/self-help-related systems have you **used**?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Computer-based instruction (e.g., CD, DVD, VCR)						
2. Computer support group (e.g., chat room, discussion forum)						
3. Digital or tape recorder						
4. Internet searching (e.g., Google, directories, URLs, newspapers)						
5. Language learning and translation systems						
6. Online library database/catalog						

21. On average, how many hours per day do you spend at home?

- ☐$_1$ Less than 8 hours
- ☐$_2$ 8-11 hours
- ☐$_3$ 12-15 hours
- ☐$_4$ 16-19 hours
- ☐$_5$ 20-24 hours

22. Within the last year, which of the following home-based systems have you **used**?

	Not sure what it is$_1$	Never$_2$	Once in a while$_3$	Some of the time$_4$	Most of the time$_5$	Always$_6$
1. Garage door opener						
2. Microwave oven						
3. Home security system (e.g., visitor entry directory system, home alarm, gate access)						
4. Personal computer						
5. Programmable device (e.g., lights, thermostat, sprinkler, programmable food processor, programmable coffee maker)						
6. Robot (e.g., vacuum cleaner, lawn mower)						

23. On average, how many hours **per week** do you work (including volunteer work) in or out of the home? (For the purpose of this question you should not consider activities such as homemaking or family caregiving)

- ☐$_1$ 0
- ☐$_2$ 1 – 10 hours
- ☐$_3$ 11 – 20 hours
- ☐$_4$ 21 – 30 hours
- ☐$_5$ 31 – 40 hours
- ☐$_6$ More than 40 hours

24. Within the last year, which of the following technologies have you **used** in the context of your work?

	Not sure what it is₁	Never₂	Once in a while₃	Some of the time₄	Most of the time₅	Always₆
1. Bar code scanner						
2. Cell phone						
3. Computer						
4. Copier/scanner						
5. Recording or playback device (e.g., CD, DVD, VCR)						
6. Electronic cash register (point of sale terminal)						
7. E-mail						
8. Fax machine						
9. Internet						
10. LCD projector						
11. Multifunction telephone system (e.g., with conferencing, speaker, transfer capabilities)						
12. Pager/Beeper						
13. Personal digital assistant (PDA)						
14. Voice recorder (e.g., dictaphone, digital recording system, handheld tape recorder)						

25. For each of activities listed in the table, please indicate how important technology is to the performance of the activity.

	Not at all important$_1$	Somewhat important$_2$	Neutral$_3$	Important$_4$	Very important$_5$
1. Communication activities					
2. Customer service activities					
3. Financial transaction activities					
4. Healthcare related activities for yourself or others					
5. Home activities					
6. Learning/education/ self-help activities					
7. Leisure/hobby/ entertainment activities					
8. Shopping activities					
9. Transportation activities					
10. Use of healthcare devices in your home					
11. Work activities					

26. How much more training would you like to have in the use of technology?

- ☐$_1$ None
- ☐$_2$ A little
- ☐$_3$ Moderate training
- ☐$_4$ A lot

27. Have you had experience with computers?

- ☐$_1$ Yes
- ☐$_2$ No (Skip to Input Device Questionnaire)

28. For each input device listed below, please indicate how much experience you have had with the device in the past year.

	Not sure what it is[1]	Never used[2]	Used once[3]	Used occasionally[4]	Used frequently[5]
1. Joystick					
2. Keyboard					
3. Light-pen					
4. Mouse					
5. Rotary input knob					
6. Speech Recognition System					
7. Touch screen with finger					
8. Touch screen with stylus					
9. Trackball					

29. For each basic computer operation listed below, please indicate how much experience you have had with the operation in the past year.

	Not sure what it is[1]	Never used[2]	Used once[3]	Used occasionally[4]	Used frequently[5]
1. Delete a file					
2. Insert a disk/CD/DVD					
3. Install software					
4. Open a file					
5. Save a file					
6. Set printer options					
7. Set monitor options					
8. Transfer files					
9. Use a printer					
10. Use cut-and-paste operations					

30. For each item listed below, please indicate how much experience you have had with the item in the past year.

	Not sure what it is$_1$	Never used$_2$	Used once$_3$	Used occasionally$_4$	Used frequently$_5$
1. Apple (Macintosh) operating system					
2. CD/DVD creation software					
3. Computer graphics (e.g., Photoshop, Harvard Graphics, AutoCAD)					
4. Conferencing software					
5. Database management (e.g., Access, Filemaker, Lotus 123)					
6. E-mail					
7. Home computer network (e.g., wire or wireless)					
8. Instant messaging					
9. Internet phone					
10. Presentation software (e.g., PowerPoint, Freelance)					
11. Programming package (e.g., Basic, C++, Fortran, Java)					
12. Spreadsheet (e.g., Excel, Quattro Pro)					
13. Statistical package (e.g., SPSS, SAS)					
14. UNIX/LINUX operating system					
15. Web design software (e.g., Java, HTML)					
16. Windows operating system					
17. Word processing (e.g., Microsoft Word, WordPerfect)					

31. For each windows operation listed below, please indicate how much experience you have had with the operation in the past year.

	Not sure what it is$_1$	Never used$_2$	Used once$_3$	Used occasionally$_4$	Used frequently$_5$
1. Change audio settings					
2. Change screen settings					
3. Change network settings					
4. Click icon					
5. Close a window					
6. Empty trash					
7. Manage multiple windows					
8. Move between windows					
9. Open a window					
10. Perform operations using right click on mouse					
11. Resize a window					
12. Scroll horizontally					
13. Scroll vertically					
14. Search for files					
15. Update the clock					
16. Use drop-down menu					
17. Use windows help system					

Internet Questionnaire

The purpose of this set of questions is to assess your familiarity and experience with the Internet. Please answer all questions by placing a check mark on or filling in the appropriate response.

1. About how many hours a week do you use the Internet?

   ☐1 Never (Skip the rest of the questionnaire)

   ☐2 Less than one hour a week

   ☐3 Between 1 hour and 5 hours a week

   ☐4 Between 6 hours and 10 hours a week

   ☐5 Between 11 hours and 15 hours a week

   ☐6 More 15 hours a week

2. How long have you been using the Internet?

   ☐1 Less than 6 months

   ☐2 Between 6 months and 1 year

   ☐3 More than 1 year, but less than 3 years

   ☐4 More than 3 years, but less than 5 years

   ☐5 More than 5 years

3. Compared to a year ago, has your use of the Internet changed?

   ☐1 No change

   ☐2 Increase in use

   ☐3 Decrease in use

4. If your use has changed, please explain why in a few words (e.g., training, equipment problems, frustration)

   ____

5. What was the **primary** method that you used to learn to use the Internet?

   ☐1 I taught myself by exploring it on my own

   ☐2 I read books on how to use the Internet

   ☐3 I attended a class

   ☐4 I learned from a friend or family member

   ☐5 I used an online tutorial

   ☐6 I used a CD or videotape

   ☐7 Other ways (please specify below): ________________________

   ☐8 ------ *None of the Above* --------

6. Please specify the frequency with which you have performed each of the following activities using the Internet in the past year.

	Never used$_1$	Used once$_2$	Used occasionally$_3$	Used frequently$_4$
1. Banking/Money management (e.g., pay bills online, buy or sell stocks)				
2. Communication (e.g., e-mail, instant messaging)				
3. Community information (e.g., find information about community events or religious services)				
4. Education (e.g., participate in on-line degree or training program, search for information about educational courses or materials, use instructional/training software)				
5. Employment (e.g., post resume or search for information about employment)				
6. Entertainment (e.g., purchase tickets for cultural or entertainment events, find information about TV or radio shows, cultural or entertainment events, or information related to hobbies)				
7. Government and official issues (e.g., access a government website to download standard forms or find out information about benefits and programs)				
8. Health information (e.g., find information about an illness or order medication or health product)				
9. News information (e.g., find information about the weather, read the newspaper)				
10. Shopping (e.g., purchase clothes, search for information about a product)				
11. Travel (e.g., make airline, train, hotel, or rental car reservations, search for maps, travel information)				

Input Device and Video Game Questionnaire

The purpose of this set of questions is to assess your familiarity and experience with the Internet. Please answer all questions by placing a check mark on or filling in the appropriate response.

1. Of the input devices listed below, please indicate **ALL** devices with which you have had experience (check all that apply).

   - ☐ Keyboard
   - ☐ Mouse
   - ☐ Light-pen
   - ☐ Trackball
   - ☐ Touch Screen
   - ☐ Voice Input System
   - ☐ Joystick
   - ☐ Rotary Knob

2. Please describe your general video game experience (check all that apply)

   - ☐ never played video games
   - ☐ play video games infrequently (no more than four times a year)
   - ☐ have played video games regularly (at least once per month) for the past year
   - ☐ have played video games regularly (at least once per month) for at least a six-month period in the past five years
   - ☐ have played video games frequently (at least once per week) for at least a six-month period in the past five years
   - ☐ have played video games frequently (at least once per week) for at least a six-month period more than five years ago

3. Have played video games (Arcade, computer or home video gaming systems) in the last three months?

   ☐ Yes ☐ No

   If **Yes**, how frequently?

   - ☐ Less than one hour a month
   - ☐ Less than one hour per week
   - ☐ 1 hour but less than 5 hours a week
   - ☐ 5 hours but less than 10 hours a week
   - ☐ At least 10 hours a week

The purpose of this set of questions is to assess your familiarity and experience with technology. Please answer all questions by placing a check mark at the appropriate response.

1. How often do you communicate with other people (e.g., family members, friends, doctors, customer service representatives)?

   - ☐1 Daily
   - ☐2 Weekly
   - ☐3 Monthly
   - ☐4 Yearly
   - ☐5 Never

2. Within the last year, which of the following methods have you **used** for communication?

	Not sure what it is1	Never2	Once in a while3	Some of the time4	Most of the time5	Always6
1. Answering machine						
2. Cell phone						
3. Fax machine						
4. Internet (e.g., e-mail, chat room, videoconferencing)						
5. Telephone						
6. Videophone						

Appendix D: Participant Exclusion Description

A total of eleven participants, one younger adult and ten older adults, were replaced during these studies. If a participant was excluded for any reason, another participant from the same age group was tested using the same shape, layout, and word order as the replaced participant. Data from the replacement participant were also analyzed using the same processes and criteria before it was accepted into the study. All data have been retained in study archives.

Data from seven participants were excluded from analysis because they could not type at the minimum typing speed of 9 WPM, as assessed in the Mavis Bacon Teaches Typing software program (Cannon, 1999). One participant was excluded because she did not meet the minimum visual acuity criteria of 20/40. One participant was excluded because he used two hands in multiple trials on multiple blocks. Data from one younger adult participant was excluded because his average block entry time in eight blocks was faster than other younger adults in the same condition by more than two times the standard deviation for the respective block. Data from one older adult participant was excluded because his average block entry time in four blocks was slower than other older adults in the same condition by more than two times the standard deviation for the respective block.

Appendix E: ANOVA Results

Repeated Measures ANOVA results for accuracy
(Shape x Age x Layout x (Block)) for all 17 blocks

Source	*df*	*F*	*p*	ηp^2
		Between participants		
Shape (S)	1	0.37	0.55	0.01
Age (A)	1	6.32	*0.01*	0.10
Layout (L)	1	0.00	0.95	0.00
S x A	1	0.29	0.59	0.01
S x L	1	0.21	0.65	0.00
A x L	1	0.02	0.88	0.00
S x A x L	1	1.72	0.19	0.03
error	56	(9.97E-3)		
		Within participants		
Block (B)	16	1.08	0.37	0.02
B x S	16	0.80	0.69	0.01
B x A	16	1.53	0.08	0.03
B x L	16	1.19	0.27	0.02
B x S x A	16	0.77	0.72	0.01
B x S x L	16	1.25	0.22	0.02
B x A x L	16	0.64	0.85	0.01
B x S x A x L	16	0.80	0.69	0.01
error	896	(2.32)		

Note: Italics indicate significant *p* values ($p<.05$)

Repeated Measures ANOVA results for accuracy
(Shape x Age x Layout x (Type)) for block types

Source	*df*	*F*	*p*	ηp^2
		Between participants		
Shape (S)	1	1.03	0.31	0.02
Layout (L)	1	0.66	0.42	0.01
S x A	1	0.04	0.85	0.00
S x L	1	0.09	0.76	0.00
A x L	1	0.01	0.92	0.00
S x A x L	1	0.48	0.49	0.01
error	56	(3.0E-3)		
		Within participants		
Type (T)	3	1.74	0.16	0.03
T x S	3	0.26	0.86	0.00
T x A	3	0.67	0.57	0.01
T x L	3	0.80	0.50	0.01
T x S x A	3	0.53	0.67	0.01
T x S x L	3	0.58	0.63	0.01
T x A x L	3	0.68	0.57	0.01
T x S x A x L	3	0.16	0.92	0.00
error	168	(1.60E-3)		

Note: Italics indicate significant *p* values (p<.05)

Learning

Univariate ANOVA for Early Proportion Score
(Shape x Age x Layout) for Early Proportion Score

Source	*df*	*F*	*p*	ηp^2
	Between participants			
Shape (S)	1	4.43	*0.04*	0.07
Age (A)	1	0.70	0.41	0.01
Layout (L)	1	1.39	0.24	0.02
S x A	1	0.02	0.89	0.00
S x L	1	0.04	0.85	0.00
A x L	1	1.20	0.28	0.02
S x A x L	1	0.38	0.54	0.01
error	56			

Note: Italics indicate significant *p* values (p<.05)

Univariate ANOVA for Middle Proportion Score
(Shape x Age x Layout) for Middle Proportion Score

Source	*df*	*F*	*p*	ηp^2
	Between participants			
Shape (S)	1	19.14	*0.001*	0.25
Age (A)	1	0.01	0.93	0.00
Layout (L)	1	0.85	0.36	0.01
S x A	1	0.01	0.94	0.00
S x L	1	0.09	0.76	0.00
A x L	1	0.03	0.87	0.00
S x A x L	1	0.81	0.37	0.01
error	56			

Note: Italics indicate significant *p* values (p<.05)

Univariate ANOVA for Late Proportion Score
(Shape x Age x Layout) for Late Proportion Score

Source	*df*	*F*	*p*	ηp^2
	Between participants			
Shape (S)	1	30.47	*0.001*	0.35
Age (A)	1	0.22	0.64	0.00
Layout (L)	1	12.72	*0.001*	0.19
S x A	1	0.41	0.52	0.01
S x L	1	3.19	0.08	0.05
A x L	1	0.00	0.95	0.00
S x A x L	1	0.22	0.64	0.00
error	56			

Note: Italics indicate significant *p* values (p<.05)

Appendix F: Results for Difference Score Analysis

Univariate ANOVA for Early Shape Transfer
(Shape x Age x Layout) for Early Difference Score

Source	*df*	*F*	*p*	*ηp*^{2}
Between participants				
Shape (S)	1	3.02	0.09	0.05
Age (A)	1	7.07	*0.01*	0.11
Layout (L)	1	8.28	*0.01*	0.13
S x A	1	0.10	0.76	0.00
S x L	1	0.37	0.54	0.01
A x L	1	2.76	0.10	0.05
S x A x L	1	0.09	0.76	0.00
error	56	8.05+E05		

Note: Italics indicate significant *p* values (*p*<.05)

Univariate ANOVA for Middle Shape Transfer
(Shape x Age x Layout) for Middle Difference Score

Source	*df*	*F*	*p*	*ηp*^{2}
Between participants				
Shape (S)	1	14.09	*0.001*	0.20
Age (A)	1	0.01	0.91	0.00
Layout (L)	1	0.68	0.41	0.01
S x A	1	1.01	0.32	0.02
S x L	1	0.03	0.85	0.00
A x L	1	0.02	0.89	0.00
S x A x L	1	0.56	0.46	0.01
error	56	4.36+E05		

Note: Italics indicate significant *p* values (*p*<.05)

Univariate ANOVA for Late Shape Transfer
(Shape x Age x Layout) for Late Difference Score

Source	*df*	*F*	*p*	*ηp*^{2}
Between participants				
Shape (S)	1	30.65	*0.001*	0.35
Age (A)	1	3.56	*0.06*	0.06
Layout (L)	1	9.45	*0.001*	0.14
S x A	1	4.66	*0.04*	0.08
S x L	1	3.56	0.06	0.06
A x L	1	0.42	0.52	0.01
S x A x L	1	0.04	0.85	0.00
error	56	3.38+E05		

Note: Italics indicate significant *p* values (*p*<.05)

Comparing Difference vs. Proportional ANOVAs

Univariate ANOVA for Layout Shift Proportion Score
(Shape x Age x Layout) for Shift Proportion Score

Source	*df*	*F*	*p*	*ηp*^{2}
Between participants				
Shape (S)	1	0.34	0.56	0.01
Age (A)	1	5.98	*0.02*	0.10
Layout (L)	1	1.56	0.22	0.03
S x A	1	1.47	0.23	0.03
S x L	1	4.17	*0.046*	0.07
A x L	1	1.82	0.18	0.03
S x A x L	1	0.03	0.86	0.00
error	56	1.38		

Note: Italics indicate significant *p* values (*p*<.05)

Univariate ANOVA for Layout Shift Difference Score
(Shape x Age x Layout) for Shift Difference Score

Source	*df*	*F*	*p*	*ηp*^{2}
Between participants				
Shape (S)	1	0.44	0.51	0.01
Age (A)	1	2.30	0.14	0.04
Layout (L)	1	0.56	0.46	0.01
S x A	1	1.26	0.27	0.02
S x L	1	5.48	*0.02*	0.09
A x L	1	1.09	0.30	0.02
S x A x L	1	1.59	0.21	0.03
error	56	1.04+E06		

Note: Italics indicate significant *p* values (*p*<.05)

REFERENCES

Adler, M.H. (1973). *The Writing Machine: A History of the Typewriter*. London: George Allen & Unwin, Ltd.

Baber, C. (1997). *Beyond the desktop: Designing and using interaction devices.* San Diego, CA: Academic Press.

Balota, D.A., Cortese, M.J., Hutchison, K.A., Neely, J.H., Nelson, D., Simpson, G.B., et al. (2002). *The English Lexicon Project: A web-based repository of descriptive and behavioral measures for 40,481 English words and nonwords*. http://elexicon.wustl.edu/, Washington University.

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*, 612-637.

Bellman, T., & MacKenzie, I.S. (1998). A probabilistic character layout strategy for mobile text entry. *Proceedings of Graphic Interface '98* (pp 168-176). Toronto: Canadian Information Processing Society.

Besnard, D., & Cacitti, L. (2005). Interface changes causing accidents. An empirical study of negative transfer. *International Journal of Human-Computer Studies, 62*, 105-125.

Bradley, J.V.(1959). Direction-of-knobturn stereotypes. *Journal of Applied Psychology, 43*, 21-24

Brashers-Krug, T., & Shadmehr, R. (1996). Consolidation in human motor memory, *Nature, 382*, 252-255.

Brown, T.L., & Carr, T.H. (1989). Automaticity in skill acquisition: Mechanisms for reducing interference in concurrent performance. *Journal of Experimental Psychology: Human Perception & Performance 15,* 686-700.

Burgess, C., & Livesay, K. (1998). The effect of corpus size in predicting reaction time in a basic word recognition task: Moving on from Kucera and Francis. *Behavior Research Methods, Instruments, & Computers, 30*, 272-777.

Butterbaugh, L.C., & Rockwell, T.H. (1982). Evaluation of alternative alphanumeric keying logics. *Human Factors 24,* 521-533.

Cannon, Y. (1999). *Mavis Beacon teaches typing* (Version 10.0) [Computer software]. Novato, CA: Broderbund.

Charness, N., Holley, P., Feddon, J., & Jastrzembski, T. (2004). Light pen use and practice minimize age and hand performance differences in pointing tasks. *Human Factors 46,* 373-384.

Douglas, S.A., & Mithal., A.K. (1997). *The ergonomics of computer pointing devices.* London: Springer.

Fendrich, D.W., Healy, A.F., & Bourne, L.E. (1991). Long-term repetition effects for motoric and perceptual procedures. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 137-151.

Fisk, A.D., Cooper, B.P., Hertzog, C., Anderson-Garlach, M.M., & Lee, M.D. (1995). Understanding performance and learning in consistent memory search: An age-related perspective. *Psychology and Aging, 10*, 255-268.

Gibson, J.G. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin Company.

Hornof, A. J. (2004). Cognitive strategies for the visual search of hierarchical computer displays. *Human-Computer Interaction, 19*, 183-223.

Hutchins, E.L., Hollan, J.D., & Norman, D.A. (1985). Direct manipulation interfaces, *Human-Computer Interaction*, *1*, 311-338.

Kahn, M.A., & Franks, I.M. (2000). The effects of practice on component submovements is dependent on the availability of visual feedback. *Journal of Motor Behavior, 32,* 227-240.

Kurniawan, S.H., (2001). *Using GOMS to predict older adults' search time of health information in a hierarchical structure*. Unpublished dissertation, WayneState University, Detroit, MI

MacKenzie, I. S. (2003). Motor behaviour models for human-computer interaction. In J. M. Carroll (Ed.) *Toward a multidisciplinary science of human-computer interaction*, pp. 27-54. San Francisco: Morgan Kaufmann.

MacKenzie, I.S. & Soukoreff, R.W. (2002). Text entry for mobile computing: Models and methods, theory and practice. *Human-Computer Interaction, 17*, 147-198.

Mackinlay, J., Card, S. K., & Robertson, G. G. (1990). A semantic analysis of the design space of input devices. *Human-Computer Interaction, 5,* 145-190.

Magill, R.A., & Hall, K.G. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Science, 9,* 241-289.

McCarthy, J.D., Sasse, M.A., & Riegelsberger, J. (2003). Can I have the menu please? An eye-tracking study of design conventions. In *Proceedings of HCI2003, Bath, UK,* 401-414.

McLaughlin, A.C. (2003). *Attentional Demands of Input Devices in a Complex Task.* Unpublished master's thesis. Georgia Institute of Technology, Atlanta, GA.

Mechsner, F. (2004). A psychological approach to human voluntary movements. *Journal of Motor Behavior*, *36*, 355-370.

Meyer, D. E., Abrams, R. A., Kornblum, S., Wright, C. E., & Smith, J. E. K. (1988). Optimality in human motor performance: Ideal control of rapid aimed movements. *Psychological Review, 95,* 340-370.

Michaels, C.F. (1988). Stimulus compatibility between response position and destination of apparent motion: Evidence of the detection of affordances. *Journal of Experimental Psychology: Human Perception & Performance, 14,* 231-240.

Newell, K.M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42* 213-237.

Nielsen, J. (1999). Do interface standards stifle design creativity? *Jakob Nielsen's Alertbox August 22.* Retrieved from http://www.useit.com/alertbox/990822.html April 20, 2006.

Norman, D.A., (1990). *The Design of Everyday Things*. New York: Doubleday.

Norman, D. A., & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: Keyboard layout doesn't much matter. *Human Factors*, *24*, 509-519.

O'Brien, M.A., Rogers, W.A., Richman, M., & Fisk, A.D. (2005). *Keyboard Arrangement and Shape Effects on Text Entry*, Atlanta, GA: Georgia Institute of Technology. HFA-TR-0501.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9,* 97-113.

Plaisant, C., & Sears, A. (1992). Touchscreen interfaces for flexible alphanumeric data entry. In *Proceedings of the 36th Annual Meeting of the Human Factors Society*, Santa Monica, CA, 293-297.

Polson, P. G., & Lewis, C. H. (1990). Theory-based design for easily learned interfaces, *Human-Computer Interaction*, *5*,191-220.

Pratt, J., Chasteen, A.L., & Abrams, R.A. (1994). Rapid aimed limb movements: Age differences and practice effects in component submovements. *Psychology and Aging, 9*, 325-334.

Rayner, K., & Fisher, D.L. (1987). Eye movements and perceptual span during visual search. *Eye movements: From Physiology to Cognition.* O'Regan, J.K. (ed.) NY: Elsevier Science, 293-302.

Rogers, W.A., Fisk, A.D., & Hertzog, C. (1994). Do ability-performance relationships differentiate age and practice effects in visual search. *Journal of Experimental Psychology: Learning, Memory and Cognition 20,* 710-738.

Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Pak, R. (2005). Touch a screen or turn a knob: Choosing the best device for the job. *Human Factors, 2*, 271-288.

Salthouse, T. A. (1984). Effects of age and skill in typing. *Journal of Experimental Psychology: General 113*, 345-371.

Schmidt, R.A. (1999). *Motor Control and Learning (2nd ed.). Champaign, IL:Human Kinetics.*

Shea, C. H., & Wulf, G. (2005). Schema theory: A critical appraisal and reevaluation., *Journal of Motor Behavior*, *37,* 85-101.

Shipley, W. (1940). *Shipley Institute of Living Scale.* Los Angeles: Western Psychological Press.

Stelmach, G. E., Goggin, N. L., & Amrhein, P. C. (1988). Aging and the restructuring of precued movements. *Psychology and Aging, 3*, 151-157.

Touron, D. R., & Hertzog, C. (2004). Distinguishing age differences in knowledge, strategy use, and confidence during strategic skill acquisition. *Psychology And Aging, 19*, 452-466.

Tullis, T.S. (1983). The formatting of alphanumeric displays: A review and analysis *Human Factors, 25,* 657-682.

Walker, N., Meyer, D. E., & Smelcer, J. B. (1993). Spatial and Temporal Characteristics of Rapid Cursor- Positioning Movements with Electromechanical Mice in Human-Computer Interaction. *Human Factors, 35*, 431-458.

Walker, N., Philbin, D. A., and Fisk, A. D. (1997). Age-related differences in movement control: Adjusting submovement structure to optimize performance. *Journal of Gerontology: Psychological Sciences*, *52B*, 40-52.

Wechsler, D. (1997). *Wechsler Memory Scale III.* (3rd ed.). San Antonio, TX: The Psychological Corporation.

Wobbrock, J., Aung, H. H., Myers, B., & Lopresti, E. (2005). Integrated text entry from power wheelchairs., *Behaviour & Information Technology*, *24,* 187-203.

Wright, P., Bartram, C., Rogers, N., Emslie, H., Evans, J., Wilson, B., & Belt, S. (2000). Text entry on handheld computers by older users. *Ergonomics*, Taylor & Francis. *43***,** 702-716.

Wulf, G., & Schmidt, R.A. (1997). Variability of practice and implicit motor learning. *Journal of Experimental Psychology: Learning, Memory and Cognition 23,* 987-1006.

Zhai, S., Hunter, M., & Smith, B.A. (2002). Performance optimization of virtual keyboards. In *Human-Computer Interaction, 17*, 89-129.